(54) Title: IMPROVED PARTICLE SENSOR AND METHOD FOR ASSAYING A PARTICLE

(57) Abstract

A particle sensor (10) has a mirror cavity (79) unobstructed by masks and the like. A light detector (75) is at the mirror secondary focal point (16) and well outside the mirror cavity (79). A variation includes a beam splitter (105) and a secondary light detector (77) to improve detection of larger particles (29). A second embodiment includes a pair of elliptical mirrors (11a, 11b) offset along the light beam (31). Light reflected by the second mirror (11b) represents only changes in laser power and light scattered by gas molecules (161). The resulting signal is subtracted from that produced by the first mirror (11a) to obtain a relatively "clean" signal useful to assay very small particles (29). Another variation involves an imaging system (209) for collecting light scattered by gas molecules (161).
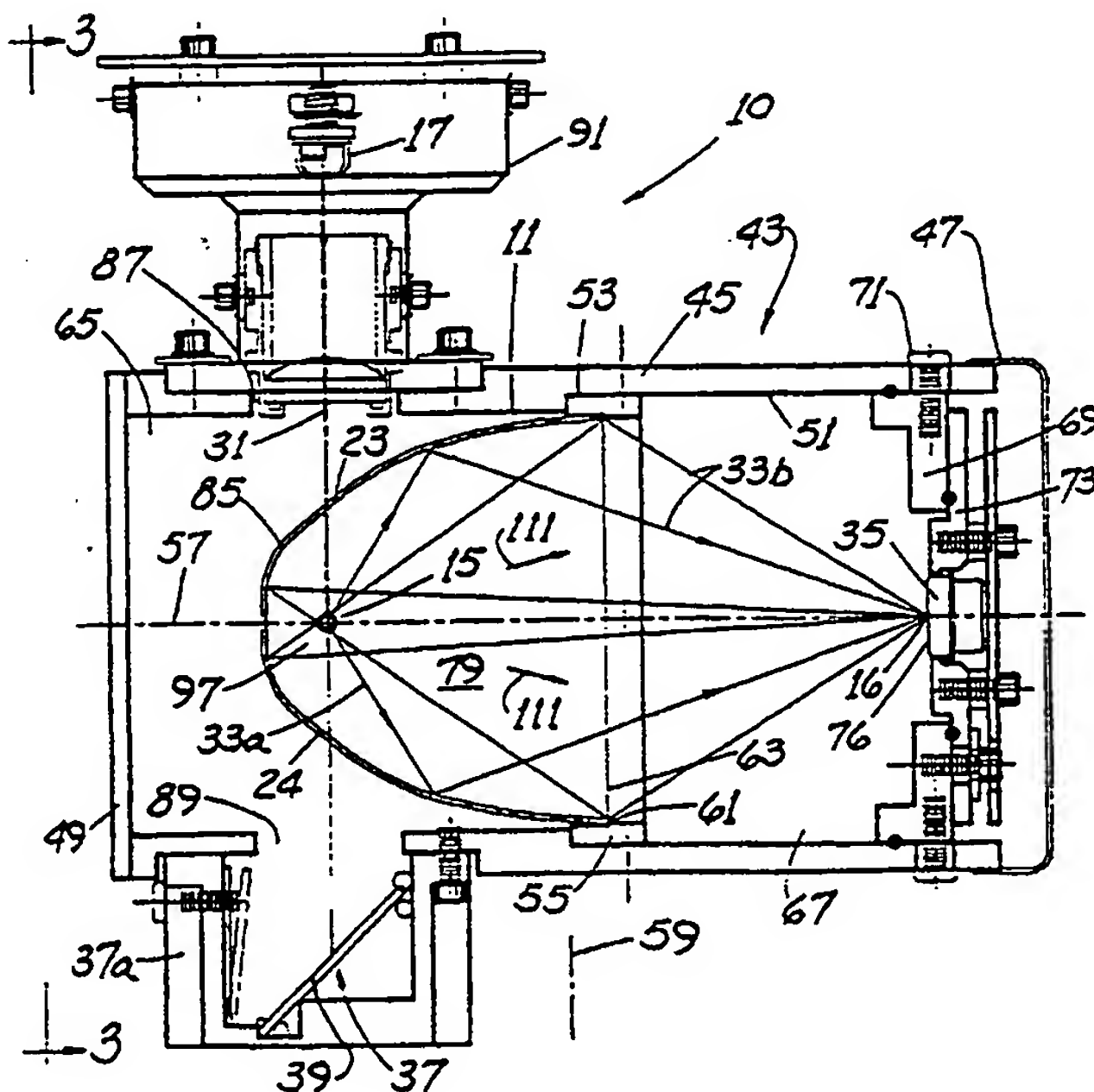
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20   <u>Title</u>:   IMPROVED PARTICLE SENSOR AND METHOD FOR ASSAYING
          A PARTICLE

      <u>Related Application</u>
          This application is a continuation-in-part of
25   application serial number 08/007,958 filed on January 22,
      1993, and now abandoned.

      <u>Field of the Invention</u>
          This invention relates generally to air quality and,
30   more particularly, to instruments for assaying airborne
      particulates.

      <u>Background of the Invention</u>
          Particle counters and sensors are used to detect
35   light scattered by particles entrained in a stream of
      fluid, e.g., in an air stream. Such counters and sensors
      draw air (with entrained particles) from a room, for

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example, and flow such air along a tube and through an
illuminated sensor "view volume" so as to obtain
information about the number and size of such particles.
Such information results from an analysis of the very
5   small amounts of light "scattered" by the particle as it
moves through the view volume.

Some types of sensors flow such air along an
enclosed transparent tube; others "project" the air and
accompanying particles at a particular flow rate (often
10   measured in cubic feet per minute) from one tube across
an open space to another tube. In sensors of the latter
type, there is no tube wall (however transparent such
wall may be) to impair light scattering and collecting.
In other words, the particle is briefly illuminated by a
15   very-small-diameter light beam as it "flies" through an
open space.

Among other uses, particle counters incorporating
particle sensors are used to obtain a measure of air
quality by providing information as to the number and
20   size of particles present in some specified volume of
air, e.g., a cubic meter of air. Even work environments
which appear to human observation to be clean--business
offices, manufacturing facilities and the like--are
likely to have substantial numbers of microscopic
25   airborne particles. While such particles are not usually
troublesome to the human occupants, they can create
substantial problems in certain types of manufacturing
operations.

For example, semiconductors and integrated chips are
30   made in what are known as "clean rooms," the air in which
is very well filtered. In fact, clean rooms are usually
very slightly pressurized using extremely clean air so
that particle-bearing air from the surrounding environs
does not seep in. And the trend in the semiconductor and
35   integrated chip manufacturing industry is toward
progressively smaller products. A small foreign particle
which migrates into such a product during manufacture can

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cause premature failure or outright product rejection
even before it is shipped to a customer. This continuing
"miniaturization" requires corresponding improvements in
clean-room environments (and in the related measuring
5   instruments) to help assure that the number and size of
airborne particles are reduced below previously-
acceptable levels. Known particle counters and sensors
have not been entirely successful in this regard.

U.S. Patent No. 4,606,636 (Monin et al.) patent
10   describes a particle analyzing apparatus into which a
particle is introduced through a tube-enclosed "view
volume." A paraboloid reflector is shown, an ellipsoid
reflector is described and the mirror cavity is
obstructed by a mask. Particle-carrying tubes can
15   refract light unpredictably and, often, the apparatus
optical system is required to be more complex as a
result. U.S. Patent No. 4,523,841 (Brunsting et al.)
shows a system used to measure aspects of biological
cells. The system uses an ellipsoid reflector, a wide-
20   area detector and a "cornucopia" type of light trap.
U.S. Patent No. 4,189,236 (Hogg et al.) patent shows a
radiation collector used for analyzing aspects of blood
cells and the like. Such collector uses light scattered
by, e.g., a cell, and twice reflected before being
25   received at a detector. U.S. Patent No. 3,248,551
(Frommer) shows an optical arrangement for sensing very
small particles such as dust or pollen.

Another disadvantage of known particle counters and
sensors becomes manifest when trying to detect very small
30   particles, e.g., 0.1 micron and smaller, and/or when
trying to detect particles present in a relatively high-
flow-volume, e.g., one cubic foot per minute, air stream.
Because the particle is very small and/or because it is
moving relatively rapidly (thus passing quickly through
35   the illuminated view volume), such particle reflects and
scatters very little light. The quantum of such light
which can be detected and accurately measured is often

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near or below the resolution and sensitivity limits of existing sensors and detectors. And, of course, the latter produces a low level of inherent "noise."

An apparent solution is to increase the quantum of
5   light reflected and scattered by a very small and/or fast-moving particles by increasing the intensity of the light beam. Such efforts have proven largely counterproductive since a more intense light source produces higher levels of random electronic or "shot"
10 noise. And as the light beam becomes more intense, the quantum of light scattered by gas molecules tends to increase, irrespective of whether a particle is also present in the view volume. Shot noise and the increasing quanta of light scattered by gas molecules
15 tends to partially or totally obscure the effect of the particle-scattered light.

To complicate matters even further, laser light sources tend to vary, even if only slightly, in output power during operation. As a consequence, the quantum of
20 light scattered by gas molecules varies with variations in power. For high powered lasers used to detect very small particles at high flow rates, such variations can be of magnitudes much higher than the shot noise or the noise inherent in an electronic detector. These
25 phenomena dramatically limit the attainable sensitivity.

An improved particle sensor which collects and analyzes a high percentage of light scattered by a very small particle and which helps neutralize the effect of light source power variations and gas molecule light
30 scattering would be an important advance in the art.

Summary of the Invention

The invention is an improvement in a particle sensor of the type having an elliptical mirror with a cavity, a
35 major axis and primary and sec ndary focal points along that axis. The sensor includes a particle-illuminating beam of light having a wavelength and extending along a

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beam axis intersecting the primary focal point. An inlet
tube introduces particles into a sensor "view volume" and
an outlet tube recovers the particles which have passed
through the view volume.

5   In the improved sensor, the mirror cavity is
unobstructed by masks and the like and a primary light
detector is at the secondary focal point well outside the
mirror cavity. This light detector is "optimized" for
detecting low-energy light like that scattered by very
10   small particles when such particles pass through the
light beam. More specifically, the sensor detects
particles down to about 0.05 micron in size.

The particles pass through the view volume, i.e., a
very small, generally cylindrical region where the light
15   beam and particle path intersect. In the improved
sensor, the view volume is a free-boundary spatial
region, i.e., a region not bounded by walls of a
particle-carrying tube or similar structure. The
particle "flies" through this region projectile-like
20   rather than being guided therethrough by a tube. When
the sensor is so arranged, particles having a maximum
dimension substantially less than the light wavelength
are efficiently detected.

In the improved sensor, the beam axis and the major
25   axis of the mirror define an included angle of about 90°
and, preferably, such axes are at 90° with the particle
path; that is, the axes and the path are orthogonal.
However, the axes and the path need not be normal to one
another; slight non-perpendicularity can be used. That
30   is, the path and the beam axis may define an included
angle of less than 90° as may the path and the mirror
major axis, the two axes and/or both axes and the path.

In a highly preferred version, the sensor has an
extended particle-detection range. That is, it can
35   detect particles larger than those sized at about 60-65%
of the beam wavelength such as are detected by the
primary detector. Accordingly, the sensor may also

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include a beam splitter plate and a secondary detector.
The secondary detector receives light reflected from the
splitter plate, thereby improving the ability of the
sensor to detect larger particles.

5   Preferably, the splitter plate and the secondary detector
are coincident with the mirror major axis and the
splitter plate is between the detectors.

A light trap "captures" that light which does not
strike a particle and is therefore not reflected by such

10   particle. In another aspect of the invention, the light
trap comprises a primary plate absorbing light of the
wavelength of the beam. In a highly preferred
embodiment, the plate comprises a light bandpass filter
having a nominal bandpass wavelength range and the

15   wavelength of the beam of light is outside such
wavelength. A secondary plate may also be included to
absorb those very small amounts of light reflected from
the primary plate.

It has been found that if light "trapping" is

20   performed outside the mirror cavity, there is a reduction
in the amount of stray light which might otherwise create
electronic "noise" in the detector circuitry.
Accordingly, the light trap, whether of one or two
plates, is outside the cavity. At least the primary

25   plate is angularly oriented with respect to the beam axis
to help prevent non-absorbed light from being reflected
back into the cavity.

A second embodiment of the inventive sensor is
particularly useful in detecting and assaying

30   (determining, e.g, the size and number of) very small
particles, especially those entrained in a high flow rate
air stream. In the second embodiment, the sensor has a
first apparatus collecting light scattered by an airborne
particle and by gas molecules and also has a second

35   apparatus collecting light scattered substantially only
by gas molecules.

The first apparatus includes an elliptical light-
reflecting first mirror having a major axis and the
primary focal point substantially coincident with the
view volume. The sensor has first and second detectors,
5   one for each apparatus. Light reflected by the mirror
impinges on the first detector which provides a first
output signal and light collected by the second apparatus
impinges on the second detector which provides a second
output signal. The sensor includes a circuit subtracting
10   the signals.

In a variant of the second embodiment, the second
apparatus comprises an imaging system having at least one
lens. Such lens collects light scattered by an airborne
particle and by gas molecules. The detector of the
15   second apparatus has a central portion and an opaque mask
preventing a part of the lens-collected light from
striking the central portion. As is explained in the
detailed description, the light which is "blocked" by the
mask is that which is reflected by a particle and by gas
20   molecules rather than light which is reflected
substantially only by gas molecules. The latter is
allowed to impact the detector.

In another variant of the second embodiment, the
second apparatus comprises a second mirror (preferably
25   elliptical with a major axis) having a focal point
displaced from the view volume, preferably displaced
along the light beam axis. The second mirror reflects
light scattered by gas molecules. The sensor has first
and second detectors and in a highly preferred
30   arrangement, the first detector is coincident with the
major axis of the first mirror and the second detector is
coincident with that of the second mirror.

As to further aspects of the sensor of the second
embodiment, the first light detector receives light
35   scattered by an airborne particle and by gas molecules
while the second light detector receives light scattered
substantially only by gas molecules and reflected by the

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second mirror. Each detector produces an output signal
(first and second signals, respectively) and both such
output signals include components resulting from (a) shot
noise (explained below), (b) random detector noise and
5   (c) changes in laser power. A subtraction circuit
subtracts from the first output signal that component of
the second output signal resulting from changes in laser
power.

As explained in greater detail below, laser light
10 sources do not provide light at an absolutely constant
intensity. This is so since the laser power varies,
perhaps by only a fraction of a percent, and light
intensity varies with it. The light received by the
first detector (scattered by a particle and by gas
15 molecules) and that received by the second detector
(scattered only by gas molecules) both evidence, by the
same changes in "scattering signal" strength, such
variations in laser power.

The signals from the detectors are processed in the
20 subtraction circuit to eliminate (from that resultant
signal which is to be analyzed) the variations in
scattering signal strength. As its name suggests, the
circuit does so by "subtracting out" the signal resulting
from the light scattered only by gas molecules. Such
25 circuit thus provides an output signal which is
substantially devoid of variations in scattering signal
resulting from changes in laser power. That is, such
output signal represents (with minor exceptions explained
below) substantially only light scattered by an airborne
30 particle.

More specifically, the improved particle sensor of
the second embodiment has a particle flow path which
intersects the light beam axis and thereby defines a view
volume with such axis. The general shape of such view
35 volume is illustrated in the drawing.

Preferred mirrors are elliptical, each having a
major axis and a primary and secondary focal point. The

mirror major axes are preferably substantially parallel
to one another. In a highly preferred arrangement of the
second sensor embodiment, the first and second detectors
are substantially at the secondary focal points of the
first and second mirrors, respectively.

Other aspects of the invention involve a method for
assaying a particle illuminated by a light beam. Such
method includes the steps of collecting a first quantum
of light scattered by a particle and by gas molecules and
collecting a second quantum of light scattered
substantially only by gas molecules. The first quantum
of light, which is scattered at a first locus such as at
the view volume, is collected by reflecting it from the
first mirror, a focal point of which is preferably at the
first locus. The second quantum of light, which is
scattered at a second locus, is collected by reflecting
it from the second mirror, a focal point of which is
preferably at such second locus.

The method also includes the steps of generating a
first signal representing the first quantum of light,
generating a second signal representing the second
quantum of light and subtracting the signals to obtain a
"clean" output signal representing substantially only
light scattered by a particle to be assayed.

The first signal generating step preferably includes
the step of positioning an elliptical first mirror having
a primary and a secondary focal point in a way that the
first mirror reflects scattered light to a first detector
at the mirror's secondary focal point. Similarly, the
second signal generating step preferably includes the
step of providing an elliptical second mirror having a
primary and a secondary focal point and positioning such
mirror in a way that the second mirror reflects scattered
light to a sec nd detector at the mirror's secondary
focal point.

It is to be appreciated that while elliptical
mirrors are preferred, other types of reflective light-

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collecting systems having suitable focusing or imaging
properties may be used in practicing the invention and
such systems are considered to be within the scope of
such invention. Further details of the invention are set
5   forth in the following detailed description taken in
conjunction with the drawing.

Objects of the Invention
     It is an object of this invention to provide an
10   improved particle sensor overcoming some of the problems
and shortcomings of the prior art.
     Another object of this invention is to provide an
improved particle sensor which helps detect very small
airborne particles.
15   Yet another object of this invention is to provide
an improved particle sensor which helps detect very small
airborne particles using once-reflected light, thereby
improving signal strength.
     Another object of this invention is to provide an
20   improved particle sensor which has an extended range for
detecting larger airborne particles.
     Yet another object of this invention is to provide
an improved particle sensor which detects particles of a
fraction of a micron in size.
25   Another object of this invention is to provide an
improved particle sensor which helps negate the effect of
variations in laser output power.
     Yet another object of this invention is to provide
an improved particle sensor having improved small-
30   particle sensitivity.
     Still another object of this invention is to provide
an improved particle sensor which efficiently traps
unreflected light.
     How these and other bjects are accomplished will be
35   apparent from the following descriptions taken in
conjunction with the drawing.

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Brief Description of the Drawing

FIGURE 1 is an isometric spatial representation of certain aspects of the improved sensor, with parts omitted.

FIGURE 2 is a cross-sectional view of the improved sensor taken from the perspective of viewing axes 2-2 of FIGURE 1 and including certain housing components and omitting other components for clarity.

FIGURE 3 is an end elevation view of the improved sensor taken from the perspective of viewing axes 3-3 of FIGURE 2.

FIGURE 4 is a graphical representation of the characteristics of a band pass light filter.

FIGURE 5 is a view of the improved sensor, similar to the view of FIGURE 3, and illustrating angular relationships described in the specification.

FIGURE 6 is a view of the improved sensor, similar to the view of FIGURE 2, and illustrating angular relationships described in the specification.

FIGURE 7 is a cross-sectional side elevation view of the improved sensor similar to that of FIGURE 2 and illustrating another variant of the first embodiment of the sensor.

FIGURE 8 is a view of the improved sensor similar to that of FIGURE 2, with parts broken away, and illustrating yet another variant of the first embodiment of the sensor.

FIGURE 9 is a spatial view showing the intersection of a light beam and a particle path to form a view volume. The beam and path are shown in dashed outline and are abbreviated in length.

FIGURE 10 is a view like that of FIGURE 2 and showing yet another variant of the first embodiment of the sens r which uses an active cavity laser as a light s urce.

FIGURE 11 is a view taken fr m the same general perspective of FIGURE 2, with parts omitted, and showing

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that variant of the second embodiment of the sensor which
uses two reflecting mirrors. Parts are omitted for
clarity.

5   FIGURE 12 is a view of the sensor of FIGURE 11 taken
from the perspective of viewing axes 12-12 of FIGURE 11.

        FIGURE 13 is another view of the sensor of FIGURES
11 and 12 showing housing and other components thereof.

        FIGURE 14 is a simplified diagram of a signal
processing circuit.

10   FIGURE 15 is a simplified light scattering diagram.

        FIGURE 16 is a diagram showing polarized light
emitted by an active cavity laser.

        FIGURE 17 is a graph showing angular light
scattering intensity for perpendicularly polarized light.

15   FIGURE 18 is a graph showing angular light
scattering intensity for parallel polarized light.

        FIGURE 19 is a view of another variant of the second
embodiment of the sensor which uses one light reflecting
system and one light imaging system. Parts are omitted

20   for clarity and the viewing volume is greatly enlarged.

        FIGURE 20 is an enlarged view of a portion of the
detector of the sensor of FIGURE 19 and illustrating an
opaque mask blocking a portion of the detector.

25   Detailed Description of Preferred Embodiments

        Understanding of the embodiments of the improved
sensor 10 will be aided by referring first to FIGURES 1-6
and, particularly, to FIGURE 1 which shows certain
components of the sensor 10 as if they were suspended in

30   space. After appreciating the relative location of those
components, the portrayals in the remaining Figures will
be more readily understood.

        The sensor 10 includes an elliptical mirror 11
having a mirror major axis 13, a primary focal point 15

35   and a secondary focal point 16. In FIGURE 1, the mirror
11 is made to appear transparent for ease of
understanding; in fact, its wall 19 is rigid and opaque

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and its interior surface 21 is highly reflective. Light
from a light source 17 passes through a beam entry
aperture 23 in the wall 19 of the mirror 11.
Simultaneously, sample air (drawn from a room, for
5   example) flows through the inlet tube 25 to the outlet
tube 27. Any particle 29 entrained therein passes
through the light beam 31 and scatters light 33a to the
mirror reflective surface 21. Light 33b once-reflected
by the mirror 11 converges at the primary detector 35 and
10 the resulting electrical signal is analyzed to provide
assay information about the particle 29 and others like
it, e.g., particle size and "count" per volumetric
measure of air. Light 33c not scattered by the particle
29 is "killed" by a light trap 37 having primary and
15 secondary plates 39, 41, respectively. In a second
embodiment of the sensor 10 (described below), the trap
37 is replaced by a reflective output mirror in a helium-
neon active cavity laser.

     Referring particularly to FIGURES 2 and 3, the
20 improved particle sensor 10 includes a somewhat elongate,
generally cylindrical, hollow body 43 having a body wall
45 and front and rear covers 47 and 49, respectively.
The interior surface 51 of the wall 45 includes a stepped
portion 53 against which a mirror support ring 55 is
25 abutted. The stepped portion 53 is concentric with the
long axis 57 of the body 43 and defines a circle, the
plane 59 of which is generally normal to such axis 57.

     The ring 55 is snugly received in the body 43 to
prevent relative ring-body movement and includes a step-
30 like, generally circular shoulder 61 diametrically sized
to receive and securely hold the elliptical mirror 11 at
its front edge. Like the portion 53, the shoulder 61 is
concentric with the long axis 57 of the body 43 and
defines a circle, the plane of which is generally normal
35 to the axis 57. The mirror includes a major axis 13
which is generally coincident with the axis 57. But for

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some relatively small apertures described below, the
mirror 11 divides the interior of the body 43 into a rear
space 65 and a front space 67.

The mirror 11 has a primary focal point 15 and a
5   secondary focal point 16, both of which are coincident
with the axes 13 and 57. Understanding of the following
aspects of the specification will be aided by brief
mention of a known characteristic of an elliptical mirror
11. Such a mirror 11 has two focal points (like focal
10   points 15, 16) along its major axis 13. Light rays 33a
scattered at the primary focal point 15 will be reflected
to the secondary focal point 16.

In one preferred embodiment, the mirror 11 is called a
"full generation, half reflector" mirror. That is, its
15   interior reflective surface 21 is generally defined (but
for some small openings like apertures 23, 24, 103 formed
therein) by rotating or "generating" an ellipse through
360° about the axis 13 and then dividing the resulting
shape (resembling the shape of a football) in half along
20   the plane 63, i.e., along a plane perpendicular to the
axis 13 and positioned halfway between the surface ends.
It is to be appreciated that the mirror 11 need not be a
full generation mirror. That is, one or more mirror
segments, each of less than 360° generation (and of
25   course aggregating to not more than 360° generation), may
be used in place of the full generation mirror 11.

Mounted within the front space 67 of the body 43 are
plural support brackets 69, each of which is affixed to
the body 43 by one or more threaded fasteners 71. Each
30   bracket 69 has a radially-inwardly projecting arm and
such arms cooperate to support a detector mounting
assembly 73 which includes a primary light detector 35.
The brackets 69, assembly 73 and detector 35 are
cooperatively arranged so that the sensing face 76 of the
35   detector 35 is coincident with the secondary focal point
16, is generally normal to the axes 13, 57 and is
positioned rearward-facing to pick up light 33b once-

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reflected from the mirror surface 21. And the
arrangement is such that the sensing face 76 can be
adjustably moved to the aforedescribed position while yet
maintaining a slight vacuum within the body 43.

5   It should be appreciated that detector 35 and/or
detector 77 may be configured to receive and react to
light received over a relatively larger area or such a
detector which is "point-like." As used in this
specification, the term "point-like" refers to a detector

10   (like detector 35 or secondary detector 77) which has
been "optimized" to detect light received on the face 76
in a very small "impact area" approaching or
approximating a point. A point-like detector is
preferred for use in the sensor 10 in many applications

15   since such detectors tend to operate faster, produce
lower background noise and, frequently, are less
expensive.

        The detector 35 is also optimized to generate a
voltage signal upon receipt of light having a wavelength

20   of about 0.8 microns or shorter and, preferably,
optimization is with respect to a specific light
wavelength. It should be appreciated that the detector
35 is connected to an electronic circuit (not shown)
which uses the detector voltage to provide information

25   relating to particle size and quantity. A preferred
detector 35 is a solid state photodiode for IR light
sources or a photomultiplier tube for blue/green light
sources.

        In one preferred embodiment, the mirror 11 includes

30   a pair of beam apertures 23, 24 through which the light
beam 31 respectively enters and exits the mirror cavity
79. As further described below, such apertures 23, 24
are in registry with the light beam 31 emanating and
extending from the light source 17 to the light trap 37.

35   The mirror 11 also includes a pair of tube apertures 81,
83 through which the inlet tube and the outlet tube 25
and 27, respectively, extend.

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Near the rather sharply curved end 85 of the mirror
11, the body 43 includes a source opening 87 and a trap
opening 89. These openings 87, 89 are in registry with
the light beam axis 31a extending through the body 43 and
5   through the mirror primary focal point 15. A light
assembly 91 is mounted adjacent to the opening 87 and has
a light source 17 supported therein along with some
optical focusing device, e.g., a suitable lens
arrangement 93. The assembly 91 itself and the juncture
10   of the assembly 91 and the body 43 are "light tight" so
that no light can enter the body 43 to interfere with
particle detection and counting.

For many applications, a laser diode is the
preferred source 17 because it is relatively small in
15   size, runs at low power levels, is relatively inexpensive
and has output characteristics resulting in a generally
uniform light intensity in the viewing volume 95 as
further described below. Merely to cite some examples of
products used for the light source 17 (the origin of the
20   reflected light 33b which is sensed at the detector 35),
today's infrared laser diodes emit light having a
wavelength of about 0.78 microns, helium/neon lasers emit
light of about 0.63 microns wavelength and light from an
argon laser has a wavelength of about 0.5 microns.

25   And the invention is not limited to use only with
those light sources 17 and detectors 35, 77 described
herein. Advances are continually being made in both and
sources and detectors of other types are and will be
considered to be within the scope of the invention.

30   Considering FIGURE 1, light from the source 17 is focused
so that the light focal point 97 is coincident with the
mirror primary focal point 15 and with the view volume
95. The greatly enlarged view of FIGURE 9 helps
understand the general shape of the view volume 95 which
35   results from the intersection of the light beam 31 and
the air flow defining a particle path 99. In FIGURE 9, a

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particle 29 is represented by a larger dot while gas
molecules 161 adjacent to the particle 29 are represented
by smaller dots.

    A light-tight trap assembly 37a is mounted at the
5   trap opening 89 and includes the light trap 37. The
improved sensor 10 uses a trap 37 that is believed to be
unique and is highly effective. The trap 37 is
preferably embodied as a primary plate 39 which absorbs
light at a wavelength or within a range of wavelengths
10   which includes the wavelength of the light emitted by the
source 17. In a highly preferred embodiment, the plate
39 is a light bandpass filter made of glass about 1 mm
thick but used in other than the intended manner.

    As an example and referring to FIGURE 4, one
15   bandpass filter is configured to have a nominal "pass
band" range of 0.35 to 0.6 microns as represented by the
bracket "P." That is, most of the light within the pass
band range passes through the filter upon striking it.
On the other hand, most light having a wavelength in the
20   0.7-0.9 micron range (as represented by bracket "A") is
absorbed by the filter rather than passing through it.

    The plate 39 is outside the cavity 79 and is
angularly oriented with respect to the beam axis 31a. In
other words, the plate 39 is non-perpendicular to such
25   axis 31a. Such plate location and orientation provides
substantial advantages. By locating the trap 37 outside
the cavity 79, any light reflected from the plate 39
(which in any event is a very small amount of light) has
virtually no opportunity to re-enter the cavity 79 and
30   create spurious light signals. Such signals can result
in electrical "noise" in the electronic detector circuit.
And angular orientation helps avoid re-directing
reflected light back into the cavity 79.

    In another preferred arrangement, the light trap 37
35   also includes a secondary plate 41 absorbing light
reflected from the primary plate 39. Since the purpose
of the trap 37 is to "kill" light 33c which does not

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strike a particle 29, the secondary plate 41 is also
selected to absorb light of the wavelength of the beam
31.

Referring further to FIGURE 3, the inlet tube 25 and
5   outlet tube 27 provide a path 99 along which airborne
particles 29 travel for analysis. As each particle 29
exits the distal end 101 of the tube 25, it passes
through the view volume 95 and is drawn (by slight vacuum
in the outlet tube) into the outlet tube 27 for ultimate
10 disposal. In that version of the sensor 10 shown in
FIGURES 1, 2 and 3, the path 99 defines an included angle
of about 90° with the beam axis 31a and the major axis 13
and the path 99 and the axes 13, 31a are thereby said to
be orthogonal. However, the improved sensor 10 is
15 operable even though the axes 13, 31a and the path 99 are
not orthogonal. That is, any two or all of the axes 13,
31a and the path 99 may define an included angle of
somewhat less than 90° therebetween and still fall within
the scope of the invention. Such relationship is
20 represented in a greatly exaggerated way by FIGURES 5
and 6.

In a variant of the first embodiment, shown in
FIGURE 7, the inlet tube 25 and the outlet tube 27 both
project into the cavity 79, the former through a small
25 aperture 103 at the mirror end 85. Like the particle
path 99 provided by them, the tubes 25, 27 are coincident
with the mirror major axis 13. The tubes 25, 27 are of
sufficiently small diameter that they do not obstruct the
cavity 79 and, particularly, do not materially obstruct
30 light rays 33a scattered by a particle 29. It is to be
understood that connections of the tubes 25, 27 and other
hardware to the body 43 is, like the attachment 37a, 91
of the assemblies, in such a way that ambient light
cannot enter the body 43.

35 In yet another variant of the first embodiment,
shown in FIGURE 8, the sensor 10 has an extended
particle-detection range. That is, it can detect

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particles 29 larger than those having a size below about
60-65% of the beam wavelength. The sensor 10 includes a
beam splitter 105 having a relatively flat plate of
ordinary optic-quality, uncoated glass of a thickness on
the order of 1-1.5 mm. The splitter 105 reflects a few
percent, e.g., 4%, of the light 33b impinging thereon and
such reflected light 33d is directed to a secondary
detector 77. The secondary detector 77 is preferably a
low-gain detector selected to "process" reflected light
pulses from particles 29 so large that such scattered and
reflected light 33a, 33b would exceed the dynamic voltage
range of the primary detector 35. The aforementioned
plate thickness represents a reasonable compromise
between acceptable plate cost and a plate which
substantially avoids "double image" problems as may
result when light reflects from both plate surfaces.

The detectors 35, 77 face one another, the splitter
105 is positioned between them and the splitter 105 and
the detector 77 are generally normal to the major axis
13. And the secondary detector 77 is located coincident
with the focal point 107 of the light beams 33d reflected
by the splitter 105.

In operation, air drawn from a "clean room" and
(inevitably) having at least a few particles 29 entrained
therein flows into the proximal end 109 of the inlet tube
25 and is drawn away through the outlet tube 27. As a
particle 29 passes through the view volume 95, the beam
31 strikes the particle 29 and light 33a is therefore
scattered. A substantial portion of the scattered light
33a strikes the mirror 11 and is once-reflected to the
primary detector 35. The resulting voltage signal is
analyzed in a known way to provide information about
particle size and about the number of particles 29 in,
say, a cubic meter of clean room air.

The advantages of the first embodiment of the
improved sensor 10 are several. With known sensors, the
percentage of the particle-scattered light that is

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"collected" by the mirror and detector for analysis is in
the low to middle 80's. In the first embodiment of the
sensor 10, a scattered light collection percentage in the
low 90's results. And when greater amounts of scattered
5   light can be collected, the intensity of the beam 31 can
be reduced. Such reduction is certainly not trivial.
For example, higher intensity light sources costing $1000
or more are not unusual. With reasonable reduction in
required beam intensity, the cost of the source 17 may be
10   reduced by a factor of 10 or so.

However, situations involving extremely small
particles and/or an elevated flow rate may require a high
intensity light source. This is so since smaller
particles have less area to reflect light and faster-
15   moving particles are "in" the light beam for a shorter
period of time. Either instance results in less
reflected light and increasing the intensity of the light
source is a way to help maintain the intensity of
reflected light. This is desirable since such intensity
20   must be sufficiently great that the light can be "sensed"
by available detectors and the resulting detector signal
must be sufficiently robust to be capable of analysis by
available processing circuits and the like.

The sensor 10 of FIGURE 10 corresponds generally to
25   that of FIGURE 2 except that the light source 17 and
light trap 37 are replaced by a multi-mode active cavity
helium-neon laser 119.

The laser 119 has a plasma tube 121 as a light
source producing polarized light which exits the tube
30   through the Brewster window 123 and propagates to the
spherical output mirror 125 which completes the laser
cavity 129. It should be understood that in this type of
laser, the tube 121, the window 123 and the mirror 125
are all part of and define the cavity 129.

35   The mirror 125 reflects the light along the path 127
and back to the Brewster window 123, thereby greatly
intensifying the magnitude of useable light at the view

volume 95. It is to be appreciated that the variant
arrangements shown in FIGURES 5-7 may be used in a sensor
10 having an active cavity laser 119 in place of the
light source 17 and light trap 37 as illustrated.

5   FIGURES 11-13 illustrate one variant of a second
embodiment of the improved sensor 10; another variant of
such embodiment is described below in connection with
FIGURES 19 and 20.

           The second embodiment has particular utility in
10   neutralizing the effect of variations in laser power.
The sensor 10 includes a multi-mode active cavity helium-
neon laser 119 having a light beam 31 extending along a
beam axis 31a. Considered "three-dimensionally," the
particle-carrying air flow path 131 extends out of the
15   drawing sheet in the view of FIGURE 11 and is coincident
with the sheet in FIGURE 12. Intersection of the beam 31
and the flow path 131 defines the view volume 95 as
portrayed in FIGURE 9. It is to be appreciated that the
particle path 99 and the air flow path 131 are generally
20   synonymous.

           Referring to FIGURE 13, the sensor 10 includes a
housing 133 supporting the plasma tube 121 and the output
mirror 125. The Brewster window 123 is visible through
the access opening 135a while the mirror 125 is visible
25   through access opening 135b. A cylinder 137a has double
O-ring seals 139 and supports the first detector 35a at
the secondary focal point 16. Similarly, a cylinder 137b
supports the second detector 35b. Purge fittings 141 are
provided so that the housing 133 can be filled with
30   substantially particle-free air to avoid deposit of
particles on the window 123 or output mirror 125.

           As a first light-collecting apparatus 12, the sensor
10 includes a first elliptical mirror 11a and its primary
focal point 15 and the view volume 95, sometimes referred
35   to as a first locus, are coincident with one another.
Light rays 33b (scattered by a particle 29 and by gas
m lecules adjacent to the particle 29) are once-reflected

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by the first mirror 11a and directed to and impinge upon
a first detector 35a at the secondary focal point 16 of
the mirror 11a. Both focal points 15, 16 are along the
major axis 13 of the mirror. The first detector 35a

5   provides a first output signal and the way such signal is
used is described below.

As a second light-collecting apparatus 14, the
sensor 10 also includes a second elliptical mirror 11b
and its primary focal point 15, sometimes referred to as

10   a second locus, is displaced along (and is coincident
with) the beam axis 31a and therefore, is spaced from the
view volume 95. This second locus may aptly be referred
to as a "quasi view volume 96." Light rays (scattered by
gas molecules but not by particles) are once-reflected by

15   the second mirror 11b and directed to and impinge upon a
second detector 35b at the secondary focal point 16 of
the mirror 11b. Both focal points 15, 16 are along the
major axis 13 of the second mirror 11b. The second
detector 35b similarly provides a second output signal.

20   Understanding of the following explanation will be
aided by the following information and by recalling that
the first mirror 11a reflects light scattered by both a
particle 29 and by adjacent gas molecules 161. On the
other hand, the second mirror 11b, having its primary

25   focal point 15 spaced somewhat away from the particle
path 99, does not "pick up" light scattered by a particle
29. However, such second mirror 11b does reflect light
scattered by gas molecules 161 in the path of the light
beam 31.

30   As background information, presently-available laser
light sources vary slightly in power output and light
intensity varies with it. The light received by the
first detector 35a (scattered by a particle 29 and by gas
molecules 161) and that received by the second detector

35   35b (scattered only by gas molecules 29) both evidence,
by the same changes in "scattering signal" strength, such

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variations in laser power. But varying laser power is
not the only problem facing the designer of a highly
sensitive particle sensor.

5   Detectors (like detectors 35a and 35b) used to
"sense" reflected light are randomly struck by light
photons. Such photons cause the detector to exhibit what
is commonly referred to as "shot noise," an unwanted low-
level, random electronic pulse or "hash" which impairs
the quality of the detector output signal. And even in
10   the absence of light photons impinging thereon,
presently-available detectors exhibit random electronic
noise which is referred to herein as "detector noise" as
distinguished from photon-caused "shot noise."

        FIGURE 14 shows a block diagram processing circuit
15   163 used to detect a particle 29. As explained above,
the intensity of light scattered by gas molecules 161
will vary with minute variations in laser power which
occur over time. Such variations occur in any laser
(like laser 119) now known. Since a particle 29 flying
20   through the light beam 31 is exposed to light for but an
instant, such power variations are not noticeable as to a
particular particle 29.

        The first composite waveform 165 represents
variations in laser output power (the waveform 167 having
25   one peak 169 and one valley 171) and also represents (by
the several low-amplitude ripples 173 on the waveform
167) light scattered by gas molecules 161 in the view
volume 95. Such composite waveform 165 also includes a
brief "blip" 175 representing light scattered in the view
30   volume 95, i.e., at the first locus, by a particle 29.
This blip 175 is very brief since, it will be recalled, a
particle 29, "flying" along a path 99 at relatively high
velocity, is in the view volume 95 for an extremely short
time. Light represented by the first composite waveform
35   165 is reflected to the first detector 35a by the first
mirror 11.

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The second composite waveform 165a similarly
represents variations in laser output power (the waveform
having one peak 169a and one valley 171a) and also
represents (by the several low-amplitude ripples 173a on
5   the waveform 165a) light scattered by gas molecules 161
in the quasi view volume 96. However, the second
composite waveform 165a does not include the "blip" 175
representing light scattered in the view volume 95 by the
particle 29. Since the first focal point 15 of the
10   second mirror 11b is displaced slightly from the particle
path 99. The light scattered at the second locus (i.e.,
in the quasi view volume 96) by gas molecules 161 is
reflected by the second mirror 11b to the second detector
35b.

15   Light (represented by the composite waveforms 165
and 165a) strike the detectors 35a and 35b,
respectively, and cause each such detector to
responsively generate an output signal Es and En,
respectively, which are propagated along lines 177, 179,
20   respectively. However, it will be recalled that
detectors produce both detector noise and shot noise and
such noise is represented by the small-amplitude lines
181. Therefore, the signals propagated along the lines
177 and 179 by the detectors 35a and 35b, respectively,
25   each have characteristics representing (a) variations
resulting from changes in laser power (b) detector noise
and (c) shot noise. However, only the signal propagated
along the line 177 has a characteristic, i.e., the blip
175, representing light scattered in the view volume 95
30   by a particle 29.

It should be observed that the variations in the
waveforms 167, 167a represented by the peaks 169, 169a
and the valleys 171, 171a have a magnitude much greater
than that of the low-amplitude ripples 173, 173a. The
35   significance of this fact is that variations resulting
from changes in laser power are much more likely to

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impair sensor sensitivity by "swamping ut" the particle
blip 175 than are detector noise and shot noise.

Referring further to FIGURE 13, the first output
signal Es of the first detector 35a and the second output
5   signal En of the second detector 35b are directed to a
subtraction circuit 183 where they are processed. Such
circuit 183 (which is well-known per se) "removes" from
that signal propagated on the line 177 the waveform
propagated on the line 179 and resulting from variations
10   in laser power and from light scattered by gas molecules
161. The resulting circuit output signal "Es-En" along
line 185 is relatively "clean" and represents
substantially only light scattered by the airborne
particle 29 (the "blip" 175) accompanied by detector
15   noise and shot noise, both of which are at a low level
compared to that portion of the signal representing the
airborne particle 29.

Some of the more technically-elegant aspects of
the second embodiment of the sensor 10 should be noted
20   and appreciated. For example, the gas molecules 161 in
the cavity 187 are at the same pressure and have the same
composition, irrespective of whether they are at the view
volume 95 or the quasi view volume 96. This negates the
effect of gas pressure or gas composition changes upon
25   the light impinging on the detectors 35a, 35b and upon
the output signal Es-En.

And gas molecules 161 at the view volume 95 and at
the quasi view volume 96 are subjected to identical
variations in the intensity of the light striking such
30   molecules 161 that may result from variations in laser
power. That is to say, there is no need to "compensate"
any of the output signals Es, En or Es-En because of gas
pressure, gas composition or light intensity changes.
Thus, the second embodiment of the sensor 10 enables
35   construction of a highly-sensitive particle counter
especially well suited for particle path flow rates of

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about 1 CFM and for detecting particles 29 flowing along
such paths 99 of about 0.1 micron and smaller.

The following Table will be helpful in making a
particle counter having a particular particle sensitivity
5   and particle path flow rate:

PARTICLE SENSITIVITY	FLOW RATE	LIGHT SOURCE
0.1μm or smaller	1 CFM	HeNe mutimode active cavity or 1 W IR Laser Diode
0.2μm	1 CFM	20 MW IR Laser Diode
0.3μm or larger	1 CFM	$\leq$ mW IR/visible Laser Diode
0.05μm	0.1 CFM	fractional Watt visible laser or small beam, high power HeNe

The following information will be helpful in
appreciating additional aspects of the improved sensor
20   10. Using the wavelength of the illuminating beam 31 as
a measurement "yardstick," particles 29 of a size
nominally equal to or slightly larger than such
wavelength tend to scatter more light in a forward
direction, i.e., in the direction of beam "travel" and
25   along paths relatively close to the beam.

As particles 29 become smaller with respect to such
wavelength, light scattered by them tends to be scattered
rather equally forward and backward but nevertheless
along paths relatively close to the beam 31. And for
30   particle sizes below about 25-30% of the beam wavelength,
the amount of light scattered laterally (rather than
forward and backward) is very small.

In FIGURES 2 and 7, it will be noted that some
scattered light 33a will travel along paths represented
35   by the arrows 111, will not strike the mirror 11 and
therefore will not be reflected to the detector 35 for
analysis. From the explanation set forth above, and from

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FIGURE 15 it will be appreciated that with particles 29
which are relatively small compared to light wavelength,
most light 33a scattered by the particle 29 is, in
general, directed forward or backward as represented by
5   the arrows 115. Relatively little light is scattered
laterally as represented by the arrows 113a, 113b,
respectively. Therefore, light travelling laterally
along paths represented by the arrows 113a, 113b
constitutes a very small percentage of the total
10   scattered light.

     In a sensor 10 using a active cavity laser 119
having a Brewster window 123, light emanating therefrom
is polarized as represented by the arrows in FIGURE 16.
However, when such polarized light strikes a particle 29,
15   the light tends to be reflected in many different
directions, albeit at widely differing intensities
consistent with FIGURE 15 and the above explanation.

     For this part of the description, it will be assumed
that the plane of polarization 191 is coincident with the
20   drawing sheet showing FIGURE 15. FIGURE 17 illustrates
the angular scattered intensity for light polarized (by
reflection from the particle 29) perpendicular to the
plane 191 shown in FIGURE 16, i.e., into and out of the
paper when considering FIGURE 15. The line 193
25   represents light scattered by a 0.1 micron particle 29
while the line 195 represents light scattered by a 0.0633
micron particle 29. It is apparent that for
perpendicular polarized light, the intensity is
substantially constant, irrespective of scattering angle
30   where (in FIGURE 17) 0° scattering angle is in the
forward direction represented by the arrow 197, 90°
scattering angle is in the direction represented by the
arrows 199 and 180° scattering angle is in the direction
repr sented by the arrow 201.

35   FIGURE 18 illustrates the angular scattered
intensity for light polarized (as before, by reflection
from the particle 29) but parallel to the plane 191 shown

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in FIGURE 16, i.e., coincident with the paper when considering FIGURE 15. The line 203 represents light scattered by a 0.1 micron particle 29 while the line 205 represents light scattered by a 0.0633 micron particle

5   29. It is apparent that for parallel polarized light, the intensity is greatest in the forward and backward directions (represented in FIGURE 15 by the arrows 197 and 201, respectively) and is very small as the scattering angle approaches 90°. And at a scattering

10 angle of 90°, for example, intensity changes depending upon the particular angle of polarization under consideration.

Thus, locating the inlet tube 25 at the rear portion of the mirror 11, 11a as shown in FIGURE 7 or 11 works

15 little impairment to the light gathering qualities of the sensor 10. This is so since at least for parallel polarized light, such rear portion receives and reflects relatively little light.

FIGURES 19 and 20 depict another variant of the

20 second embodiment of the sensor 10. As a first light-collecting apparatus 12, the sensor 10 includes an elliptical mirror 11 having its primary focal point 15 coincident with the view volume 95. In other respects, the arrangement of the mirror 11 and its detector 35a are

25 substantially identical to the arrangement of the mirror 11a and detector 35a shown in FIGURE 11 and described in connection therewith.

As a second apparatus 14 collecting light scattered substantially only by gas molecules 161, the sensor 10

30 has an imaging system 209 including at least one lens 211. In a highly preferred arrangement, such system 209 has a pair of lenses 211a, 211b which may be fresnel lenses (preferred), aspheric lenses or spheric lenses. A short lens focal length is preferred for best light-

35 gathering properties. Lenses 211a, 211b gather and focus light reflected from (as portrayed in FIGURE 9) a particle 29 and from gas molecules 161.

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It is to be noted that the light rays 213, emerging
from the center of the viewing volume 95, represent light
reflected by a particle 29 while rays 215, emerging from
locations away from such center, represent light
5   reflected by gas molecules 161. To put it another way,
the "image" of the view volume 95 is projected toward the
surface of the detector 35b. Rays representing light
reflected by the particle 29 will strike the detector 35b
near its central portion 217 while rays representing
10   light reflected by gas molecules 161 strike such detector
35b nearer the perimeter 219.

In a highly preferred arrangement, the detector 35b
is configured to provide a signal representing only light
scattered by gas molecules 161. To that end, the
15   detector 35b includes an opaque mask 221 over its central
portion 217. The mask 221 blocks light reflected by the
particle 29 but permits light reflected by gas molecules
161 to strike the detector 35b. The detector 35b thus
provides a "molecules-only" signal which is subtracted
20   from the signal representing light reflected by both the
particle 29 and molecules 161.

While the principles of the invention have been
described in connection with specific embodiments, they
are shown and described by way of example and are not
25   intended to limit the invention.

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CLAIMS

1.   In a particle sensor including (a) a mirror with
a cavity, a major axis and primary and secondary focal
5   points along such axis, (b) a particle-illuminating beam
of light having a wavelength and extending along a beam
axis intersecting the primary focal point, and (c) an
inlet for introducing particles into a sensor view
volume, the improvement wherein:
10   -the mirror cavity is unobstructed;
          -a light detector is at the secondary focal point;
          and,
          -the view volume is a free-boundary spatial region,
whereby particles having a maximum dimension
15   substantially less than the wavelength are efficiently
detected.

2.   The sensor of claim 1 wherein particles are
introduced along a path, the path and the beam axis
20   define an included angle of less than 90° and the path
and the major axis define an included angle of less than
90°.

3.   The sensor of claim 1 further including a beam
25   splitter plate and a secondary detector receiving light
reflected from the splitter plate thereby improving the
ability of the sensor to detect larger particles.

4.   The sensor of claim 1 wherein:
30   -the elliptical mirror is a first mirror;
          -the primary focal point of the first mirror is
          coincident with the view volume; and,
          -the sensor includes a second mirror having a focal
          point displaced from the view volume and reflecting
35   light scattered by gas molecules.

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5.   The sensor of claim 4 wherein:

-the light detector is a first detector receiving light scattered by an airborne particle and by gas molecules;

5   and the sensor also includes:

-a second detector receiving light scattered substantially only by gas molecules and reflected by the second mirror; and,

-the signals from the detectors are processed in a

10   subtraction circuit providing an output signal representing substantially only light scattered by an airborne particle.

6.   An improved particle sensor comprising:

15   -a light beam extending along a beam axis;

-a particle flow path intersecting the beam axis and defining a view volume therewith;

-a first apparatus collecting light scattered by an airborne particle and by gas molecules, the first

20   apparatus including a mirror having a focal point substantially coincident with the view volume; and,

-a second apparatus collecting light scattered substantially only by gas molecules.

25   7.   The sensor of claim 6 including first and second detectors and wherein:

-light reflected by the mirror impinges on the first detector providing a first output signal;

-light collected by the second apparatus impinges on

30   the second detector providing a second output signal; and,

-the sensor includes a circuit subtracting the signals.

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8.   The particle sensor of claim 7 wherein the
second apparatus includes:
      -an imaging system having at least one lens; and
      -a detector having a central portion and an opaque
5   mask preventing light from striking the central
      portion.

9.   A method for assaying a particle illuminated by
a light beam and including the steps of:
10   -detecting a first quantum of light scattered by a
      particle and by gas molecules;
      -detecting a second quantum of light scattered
      substantially only by gas molecules.

15   10. The method of claim 9 wherein:
      -the step of detecting the first quantum of light
      includes reflecting the first quantum of light from
      a first mirror;
      -the step of detecting the second quantum of light
20   includes reflecting it from a second mirror.

      11. The method of claim 9 wherein the second
quantum of light is detected by imaging it toward a
detector.
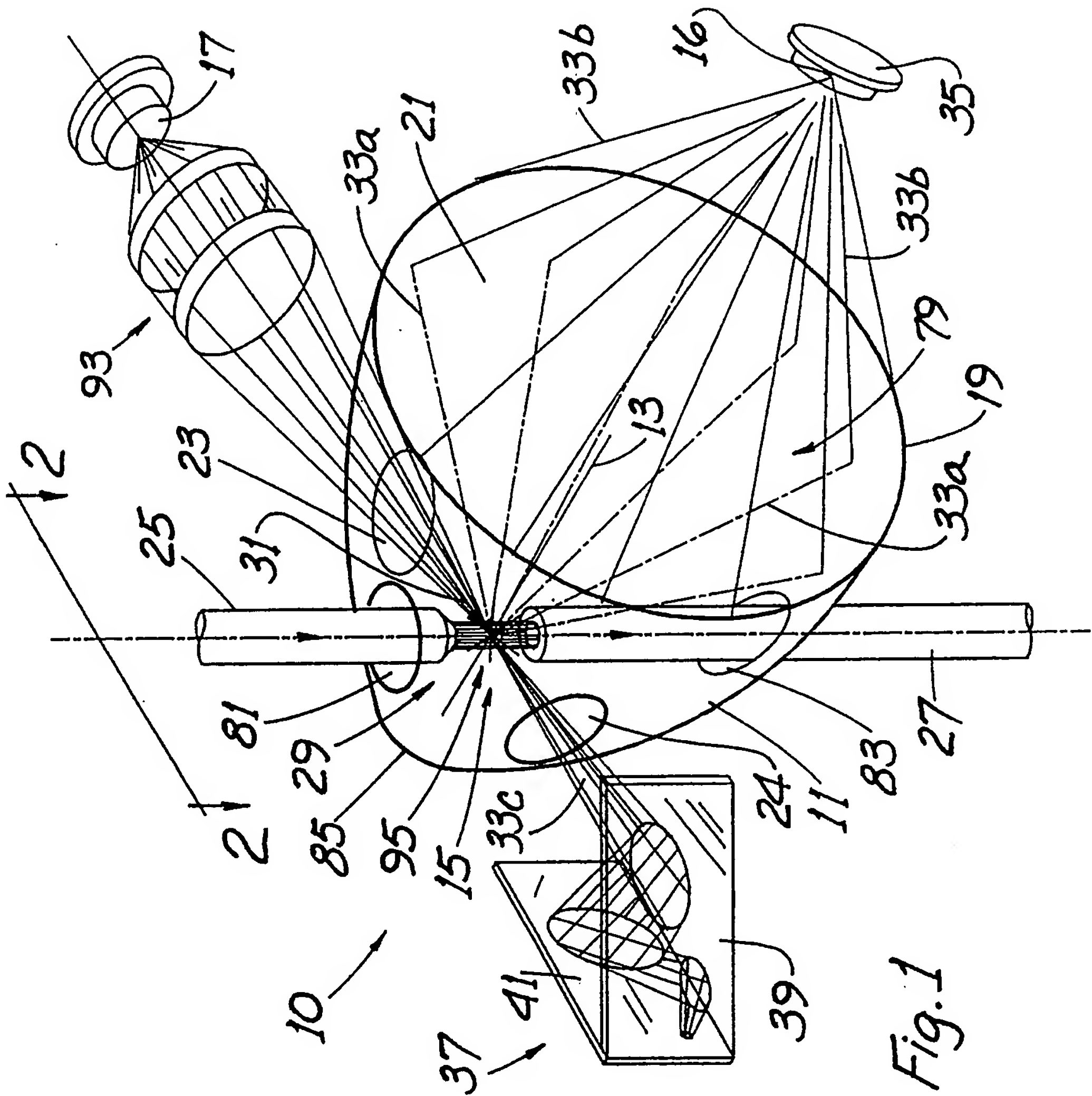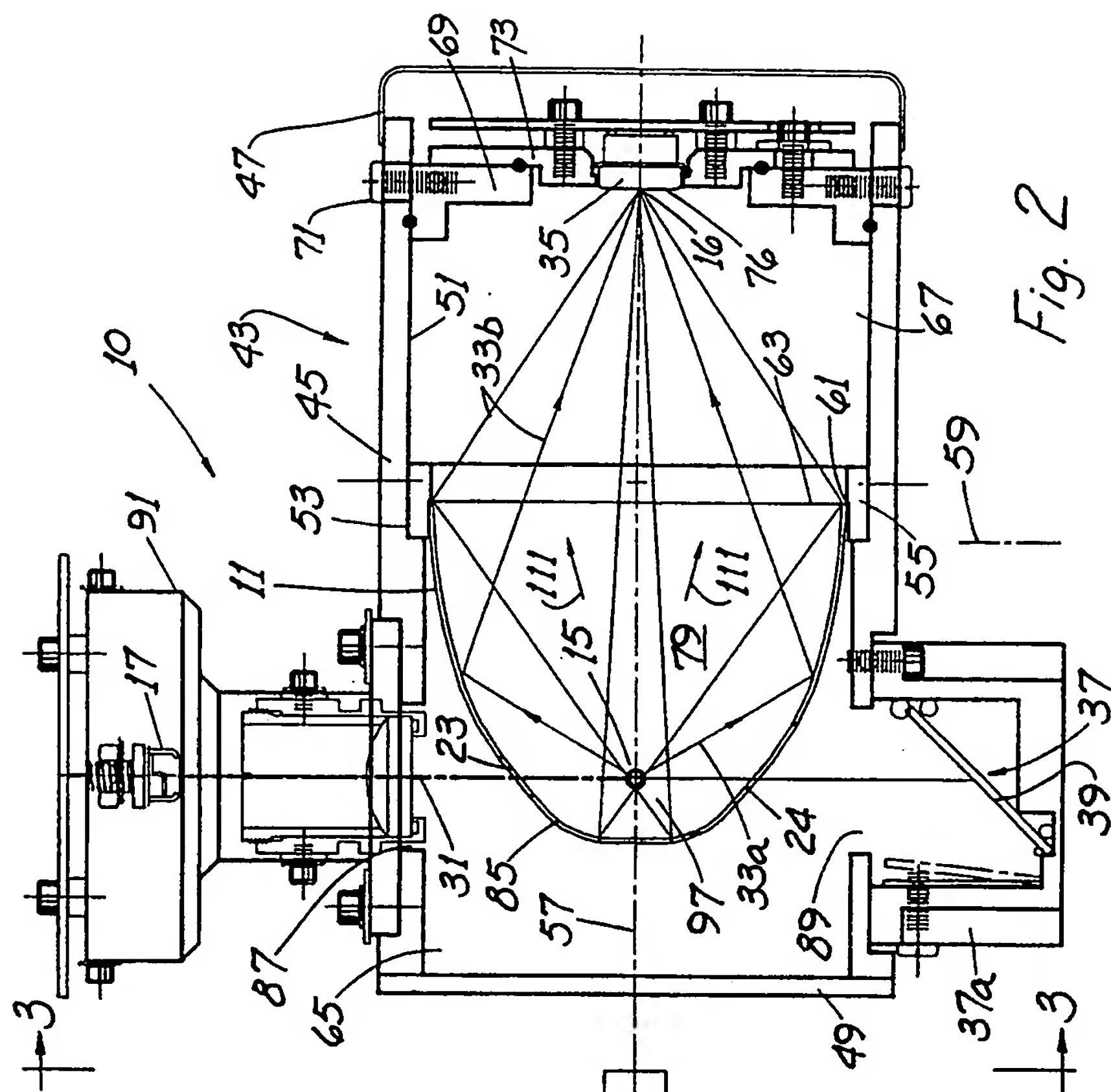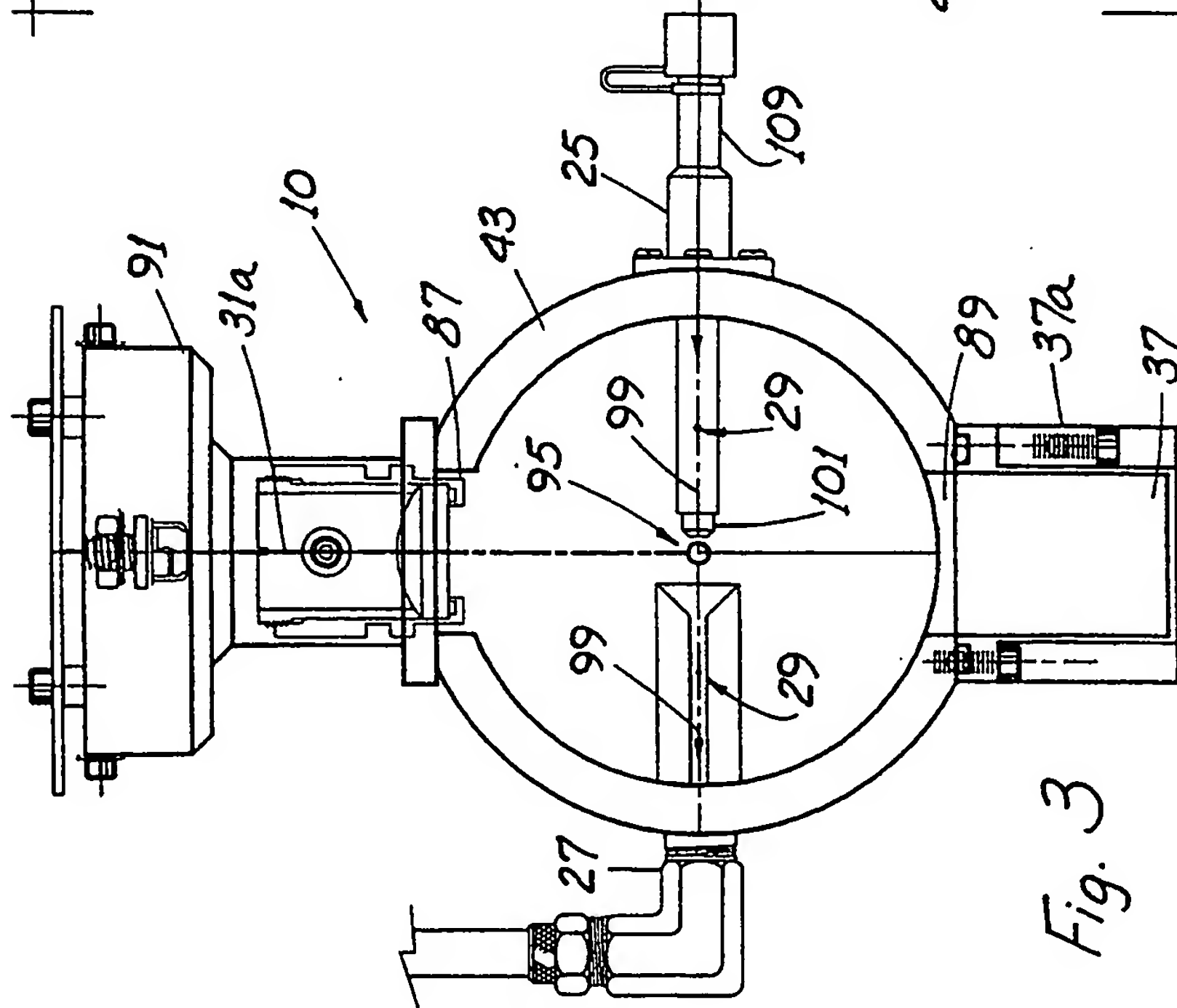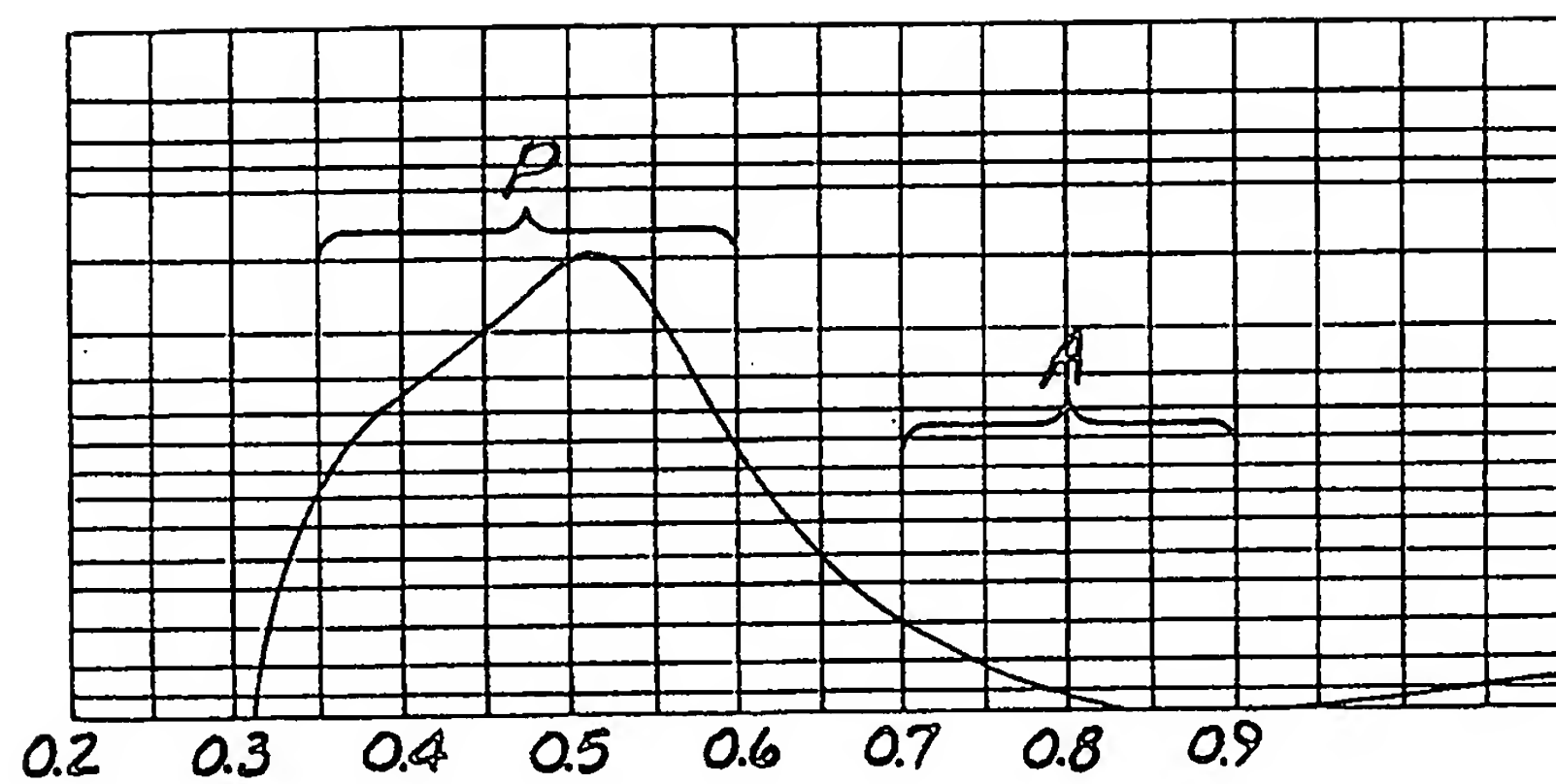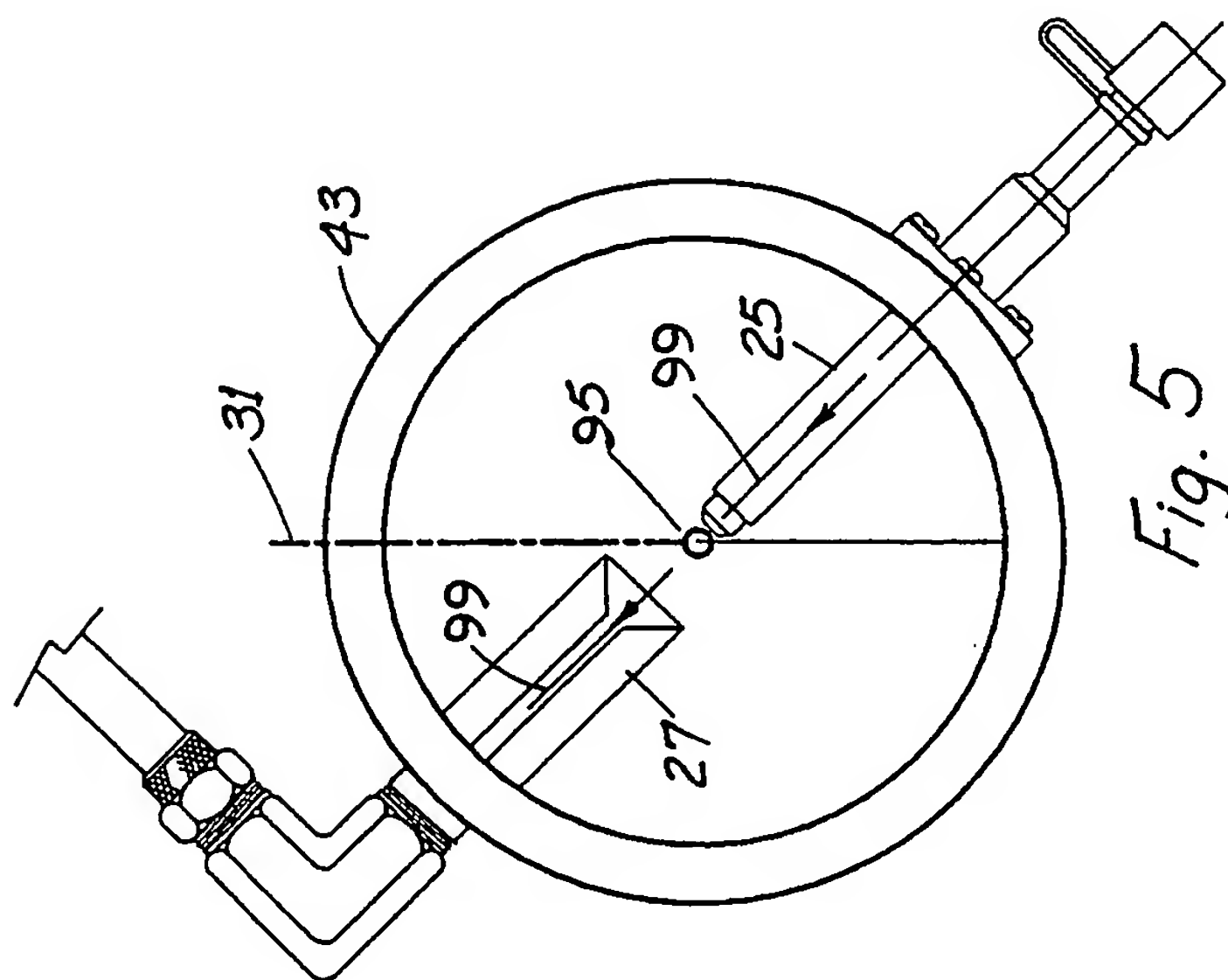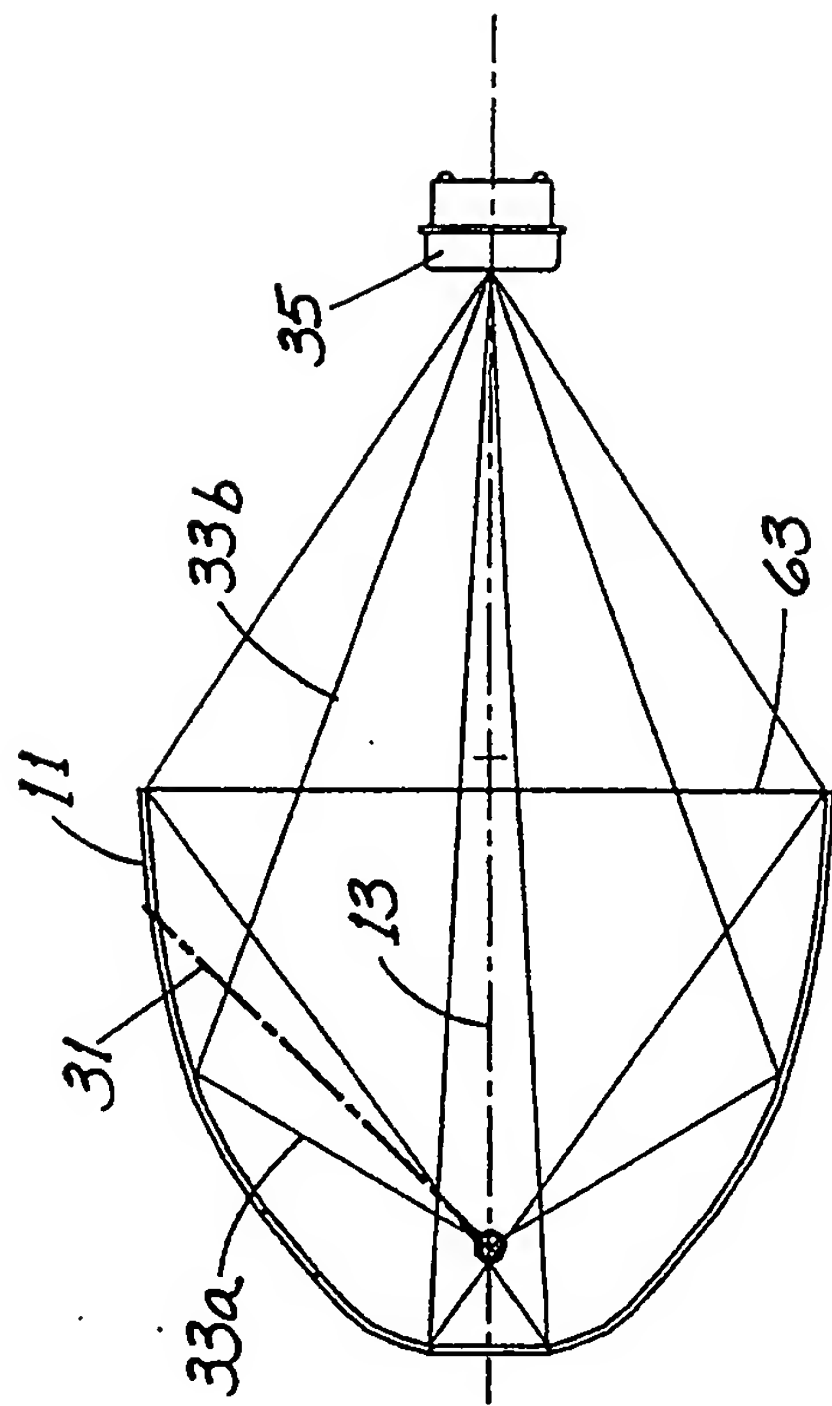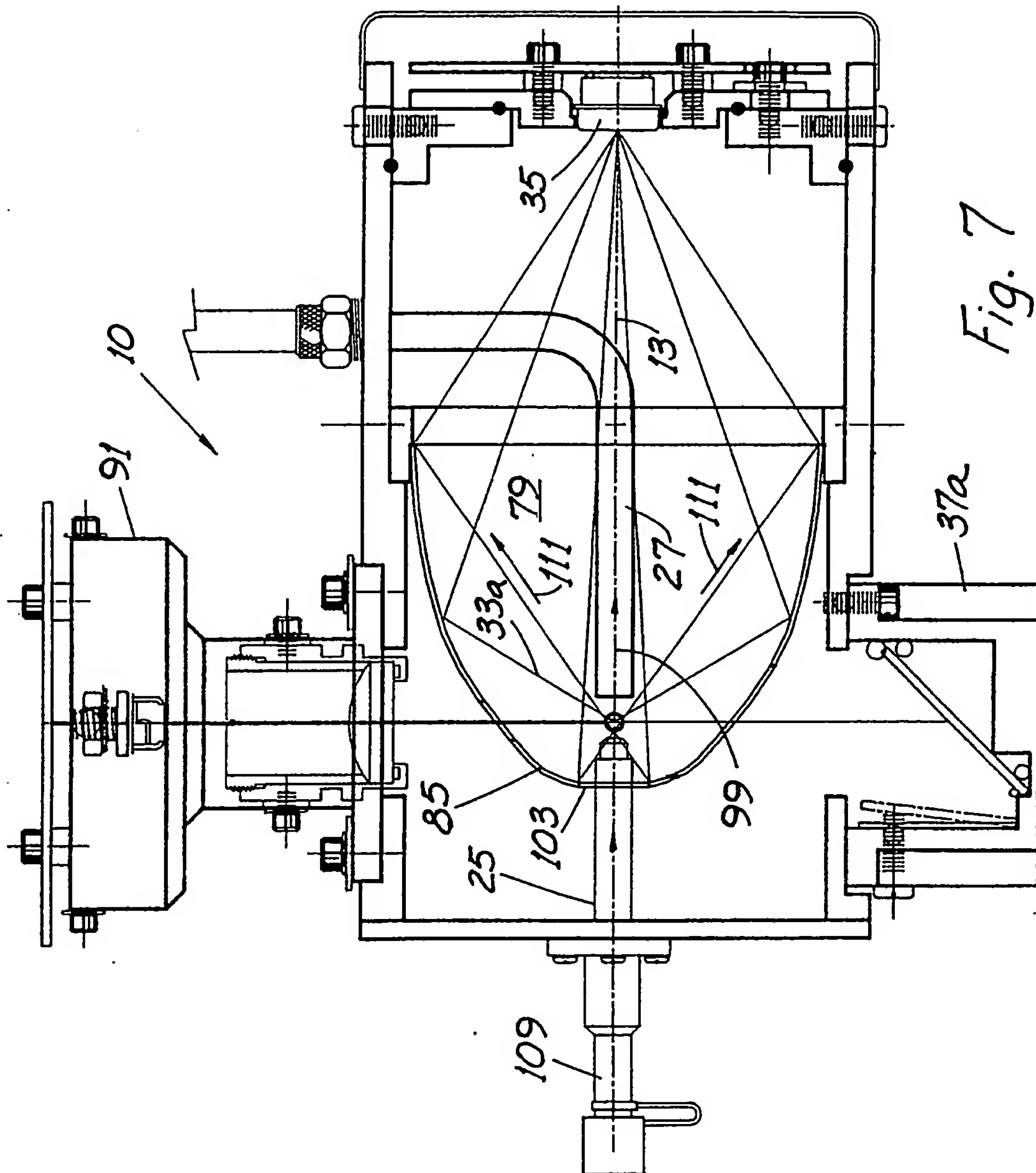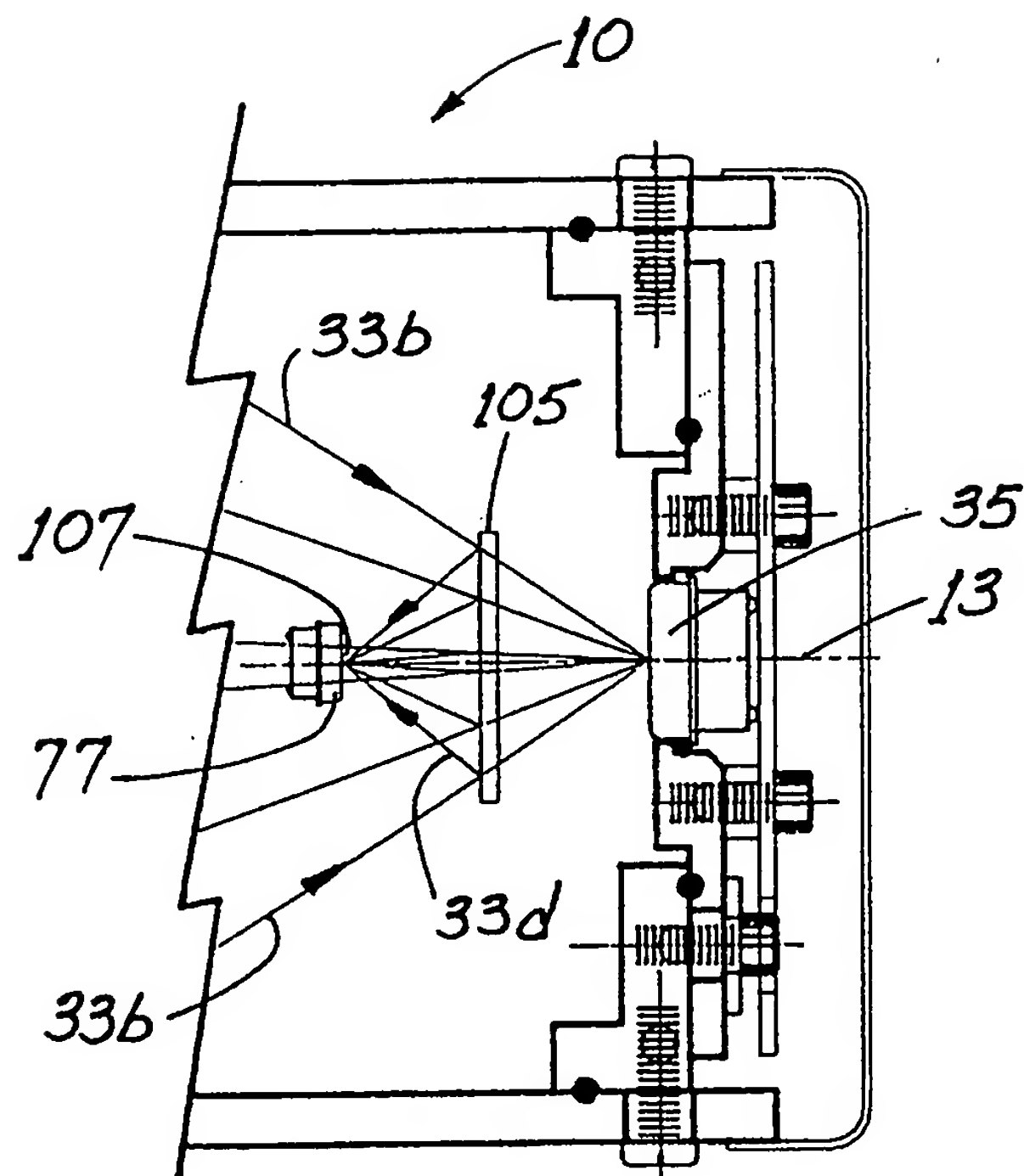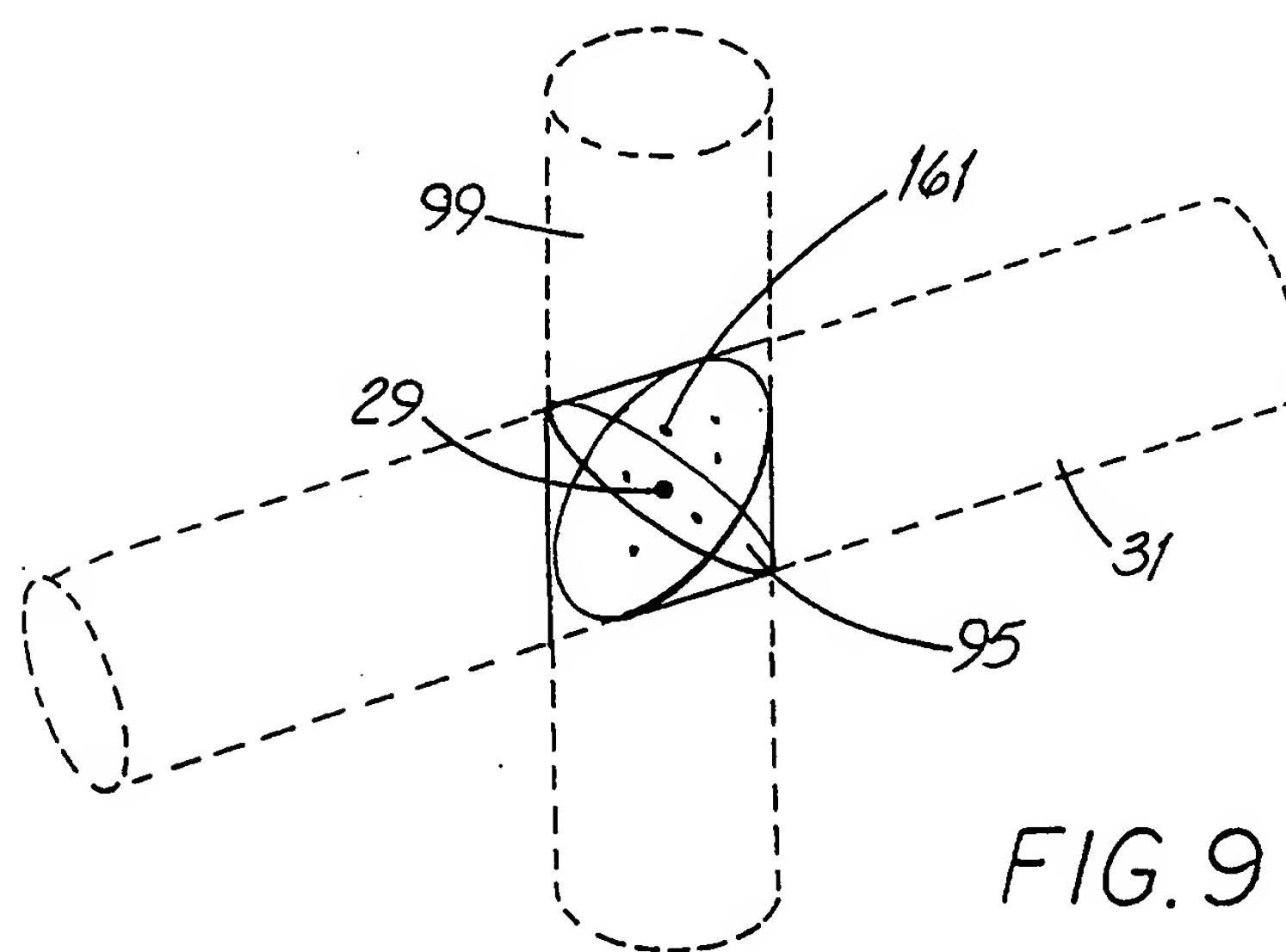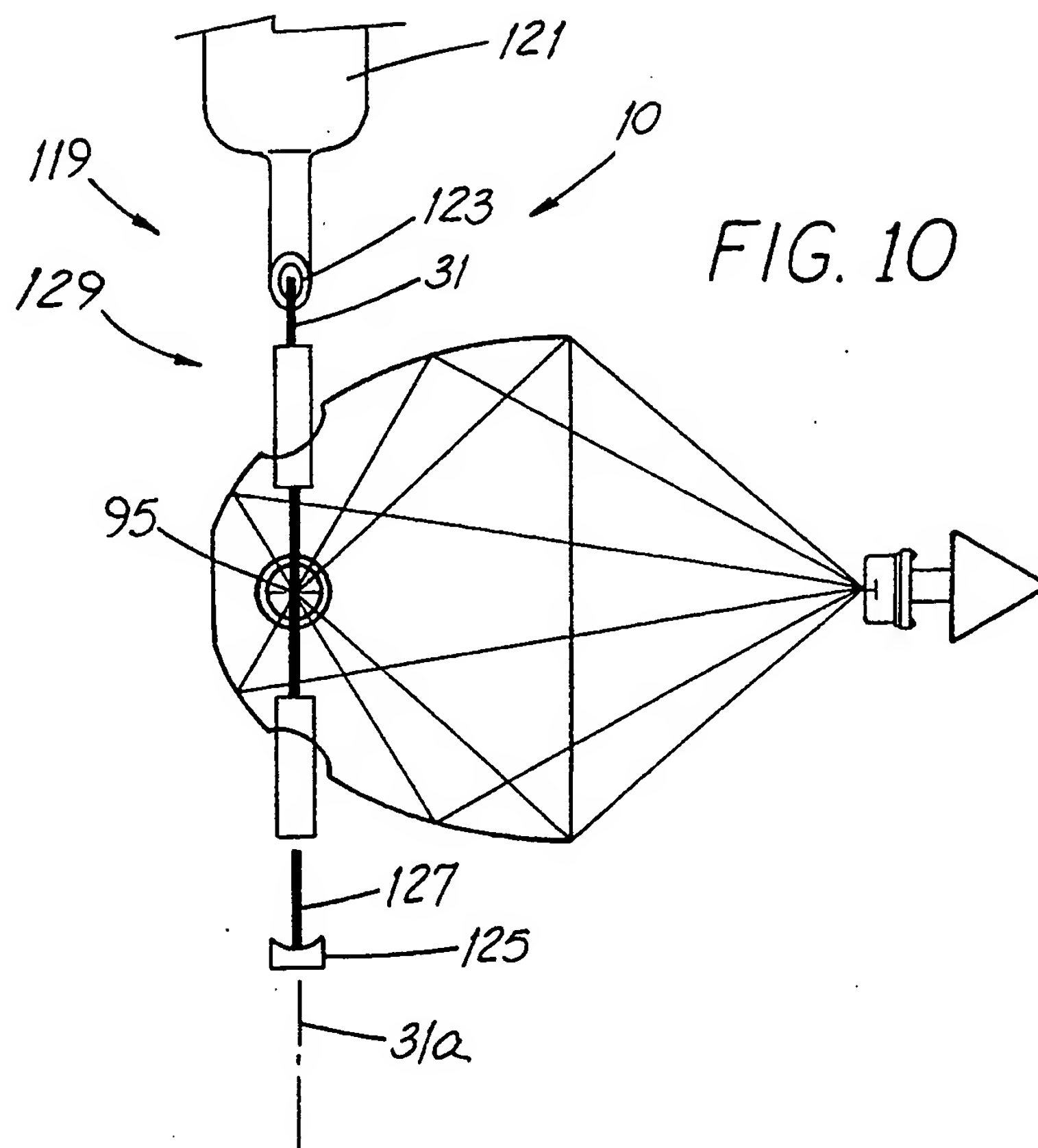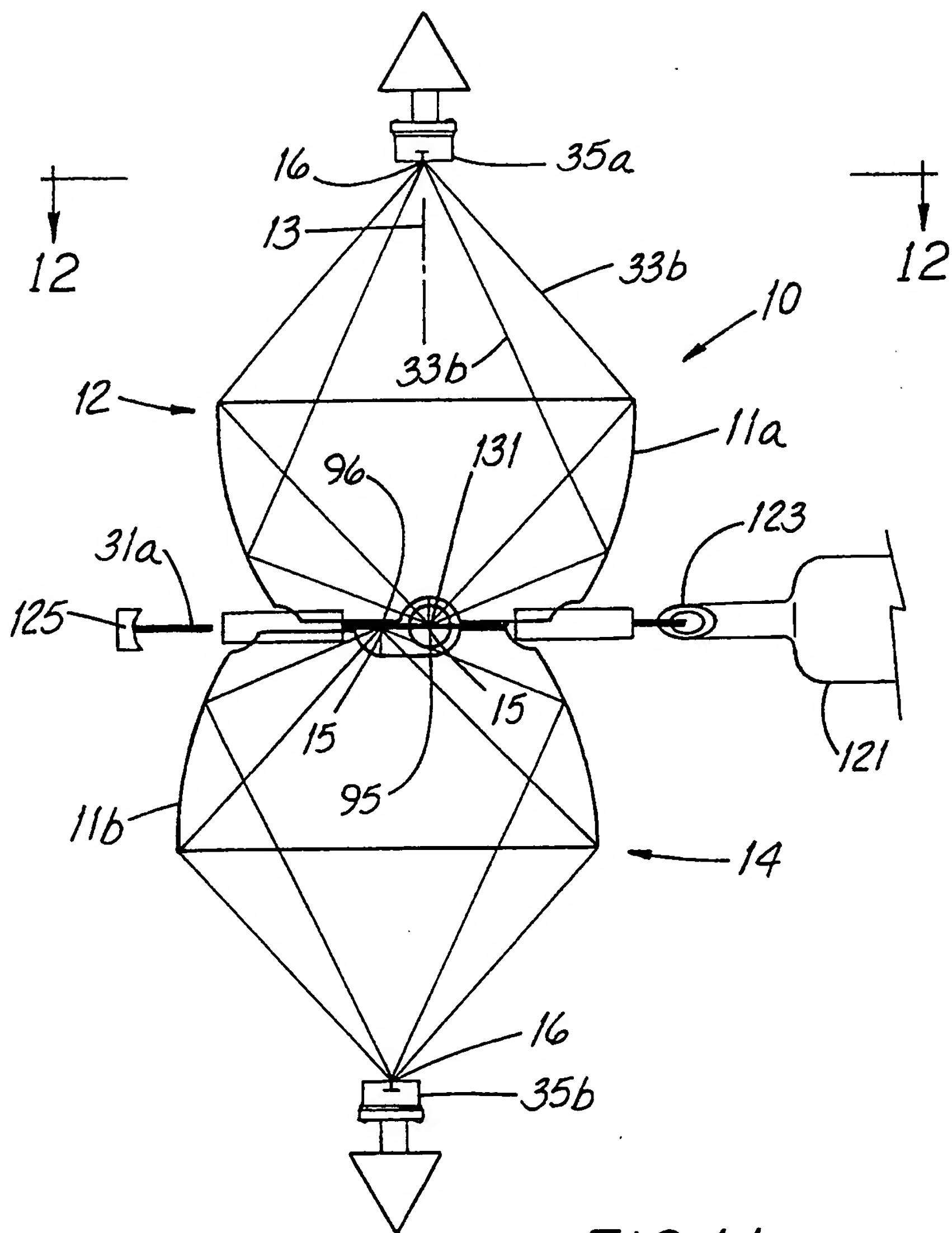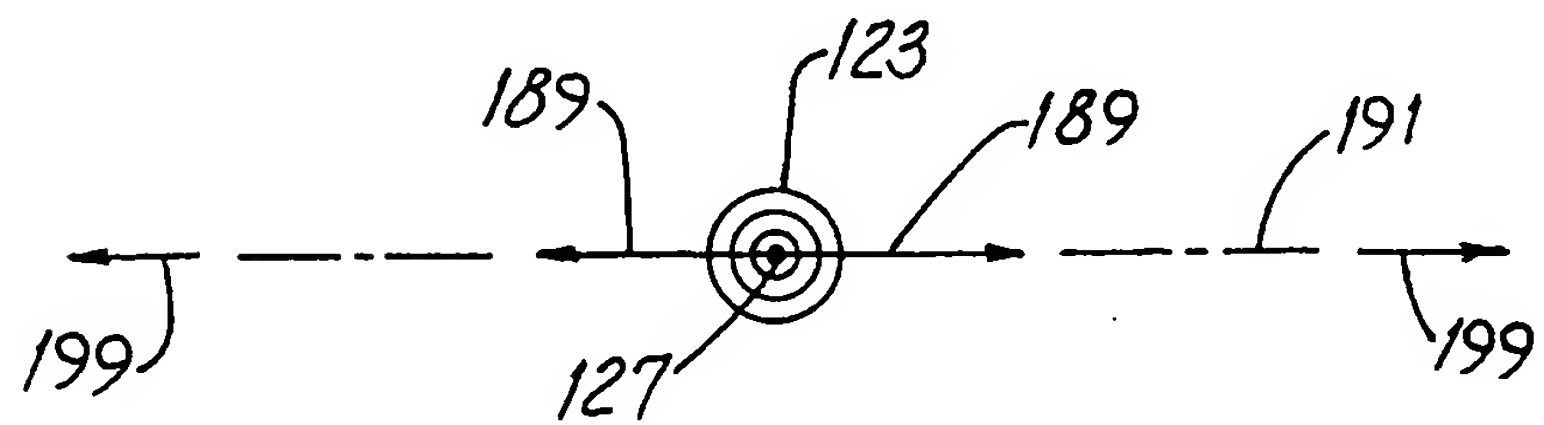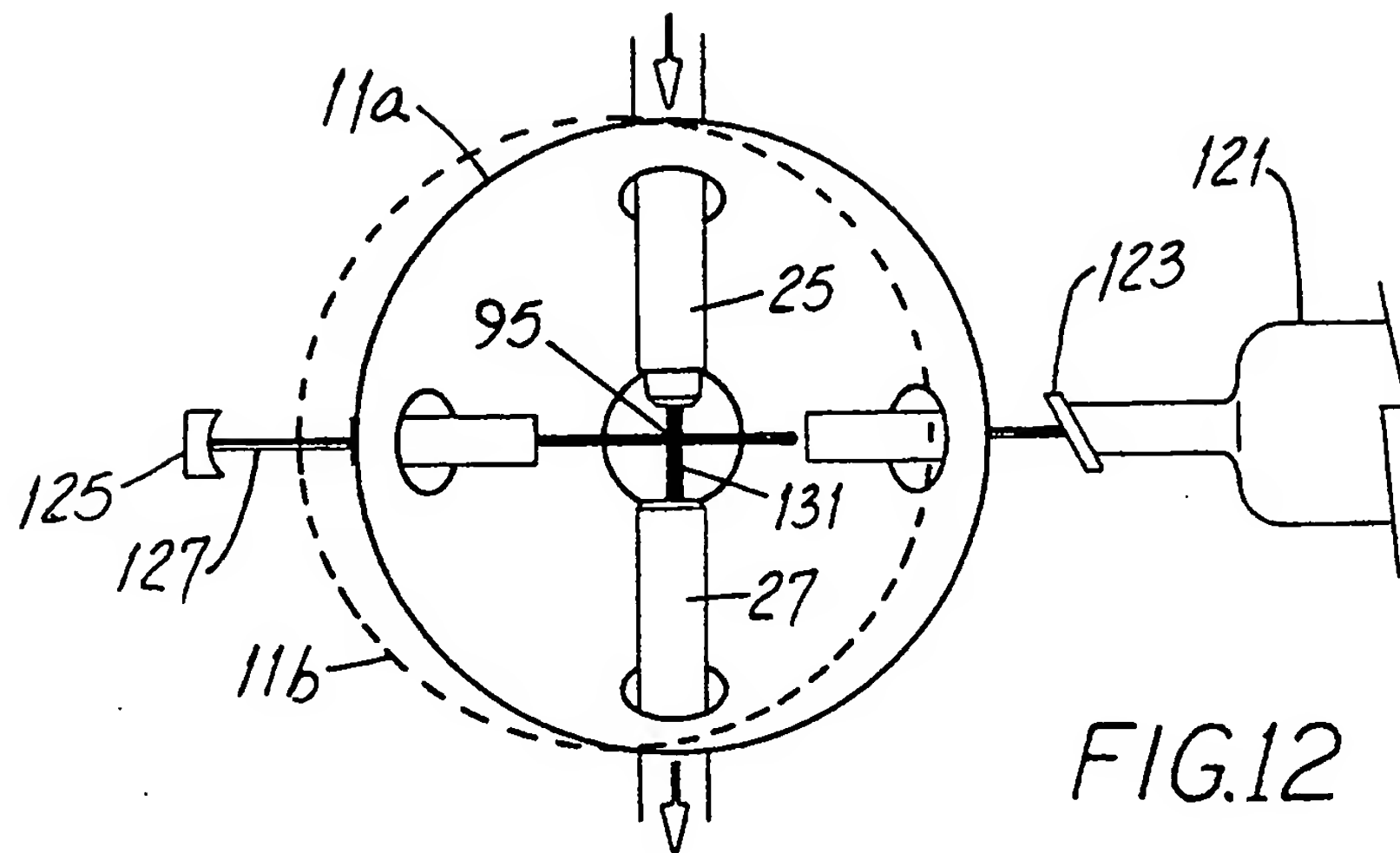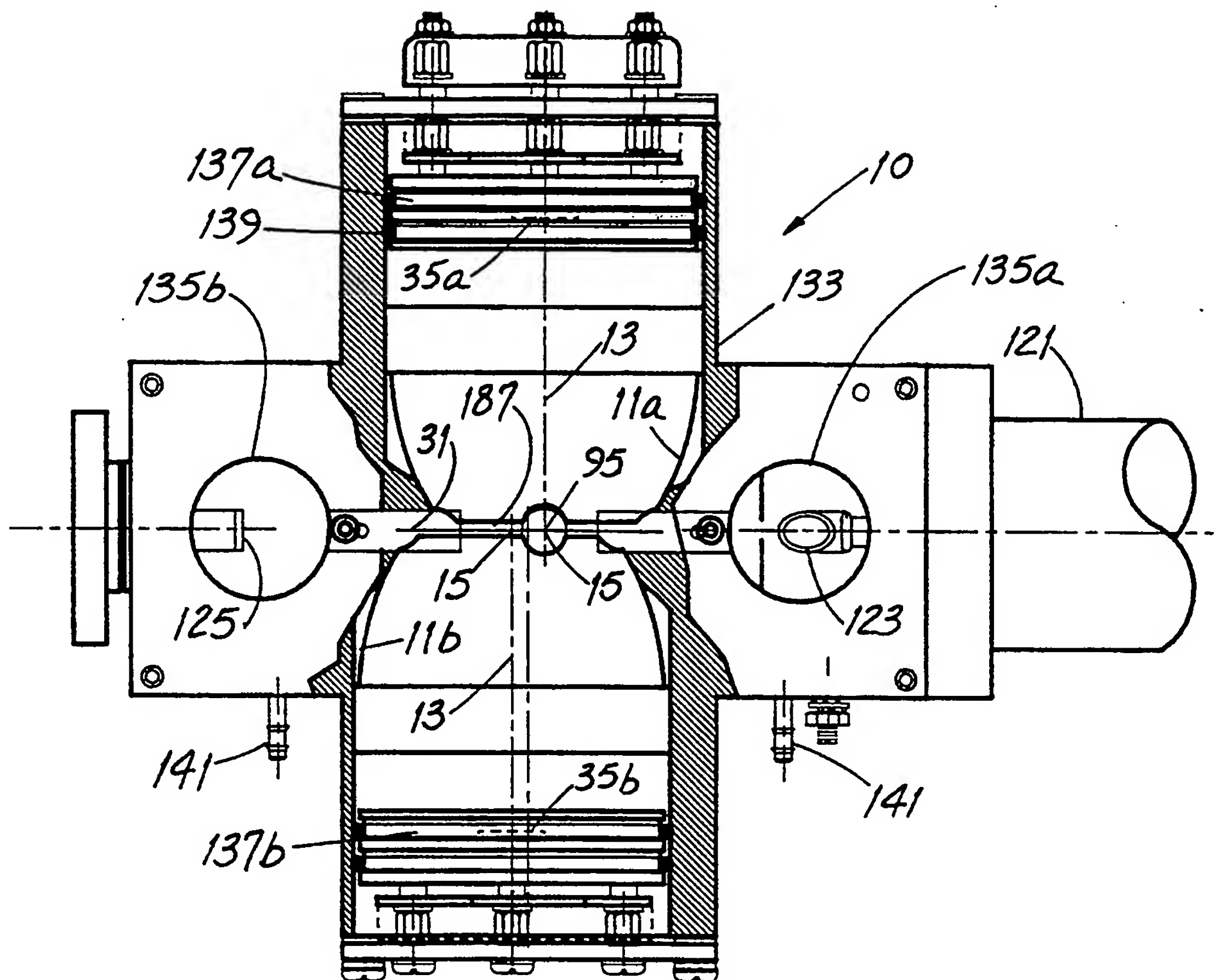
25

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 6

Fig. 5

5 / 14

Fig. 7

Fig. 8

FIG. 10

FIG. 9

FIG.11

FIG.12

FIG.16

FIG.13

FIG. 14

FIG. 15

FIG.17

FIG. 18

FIG.19

FIG. 20
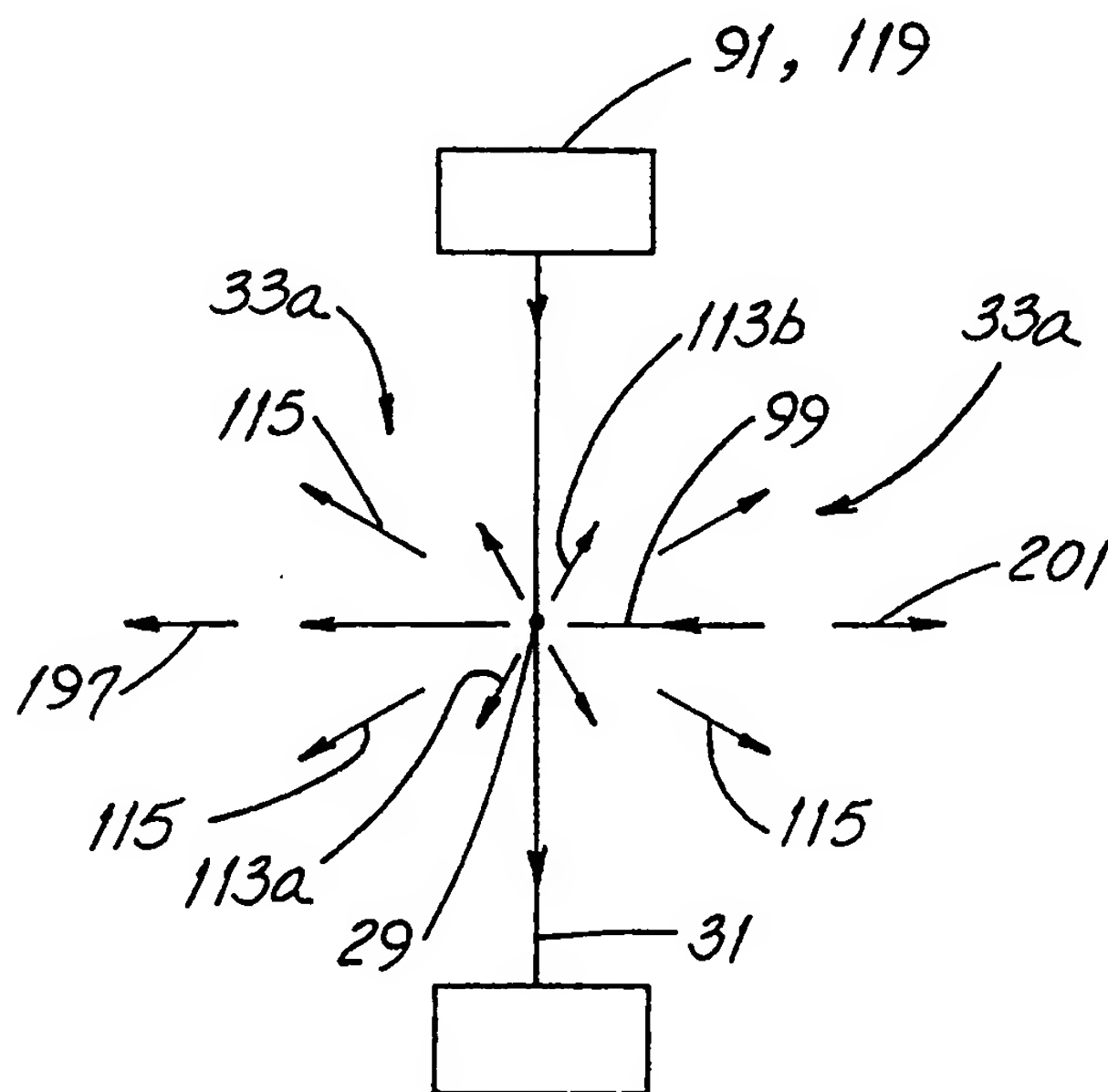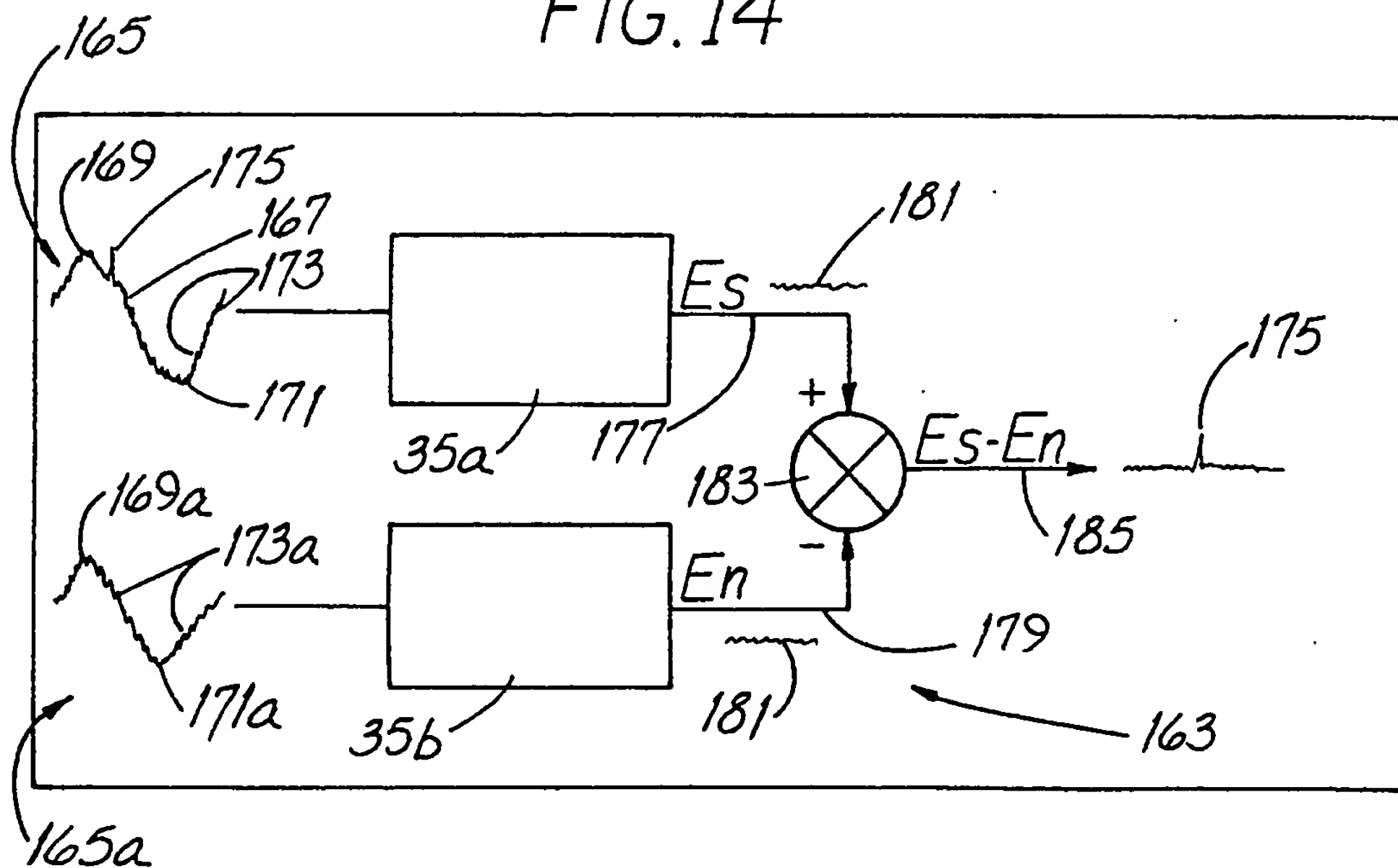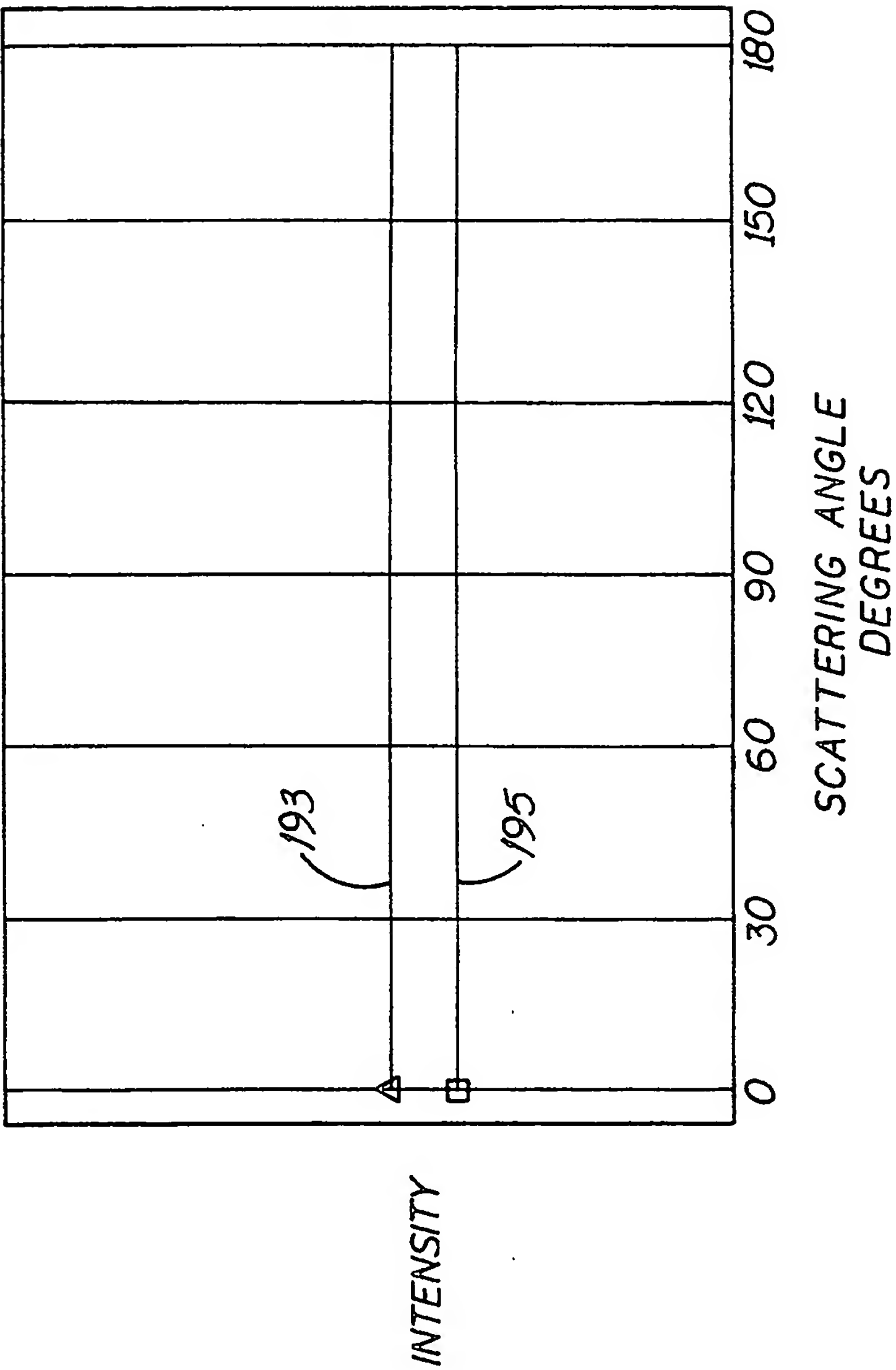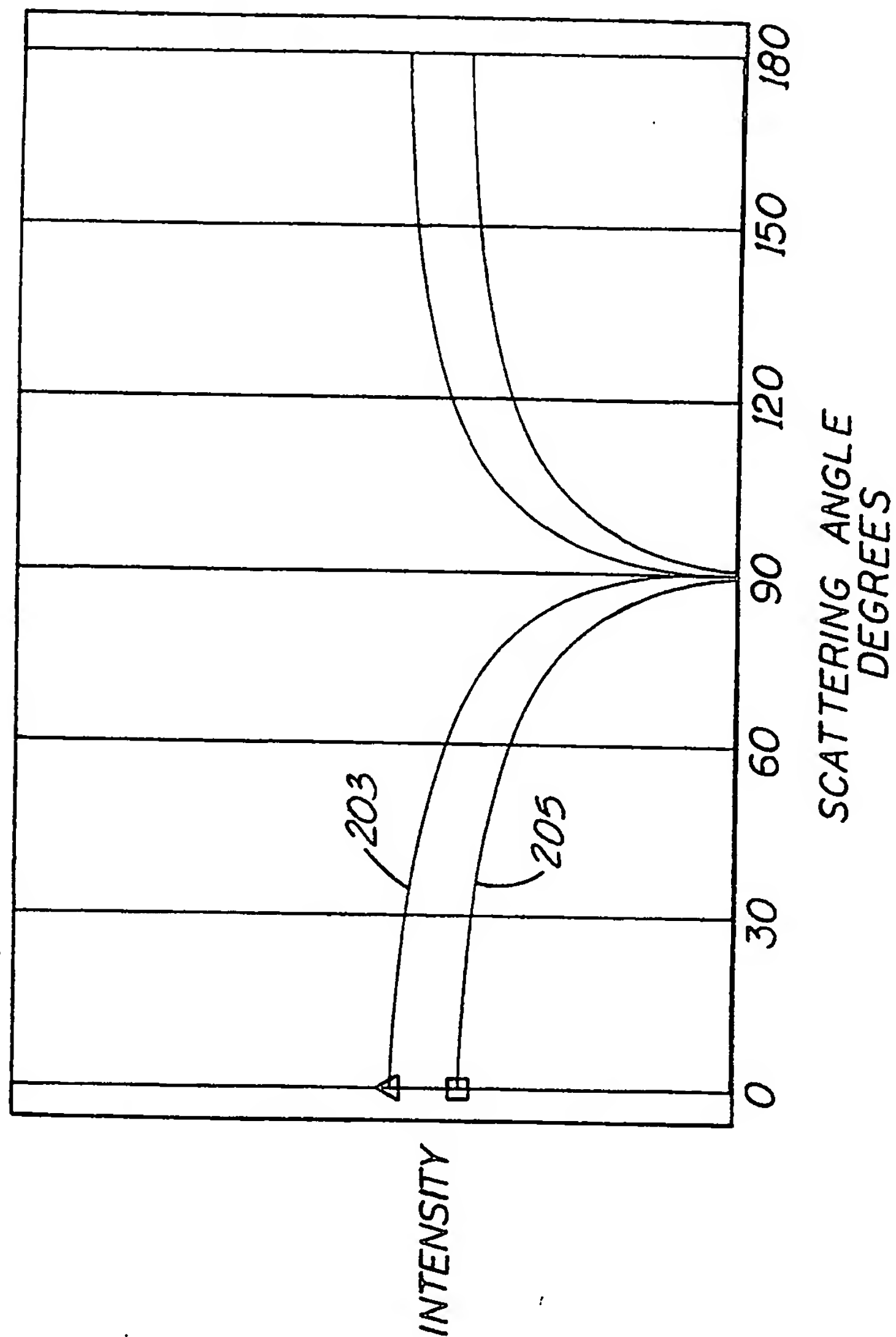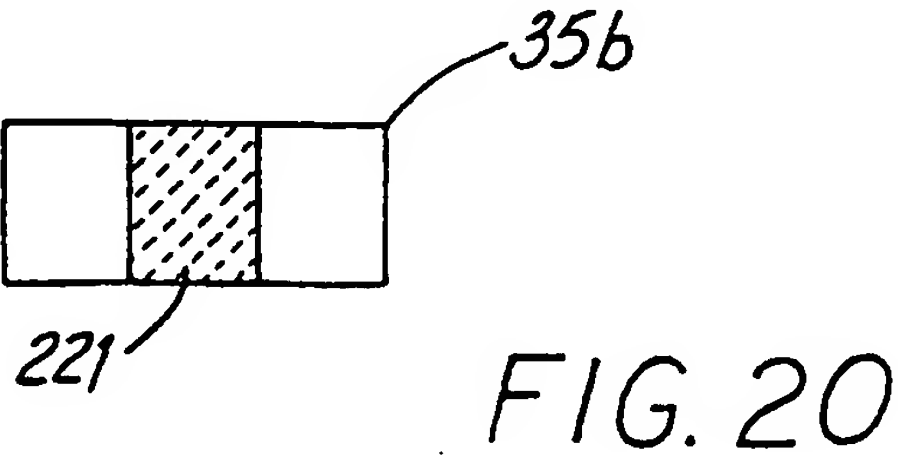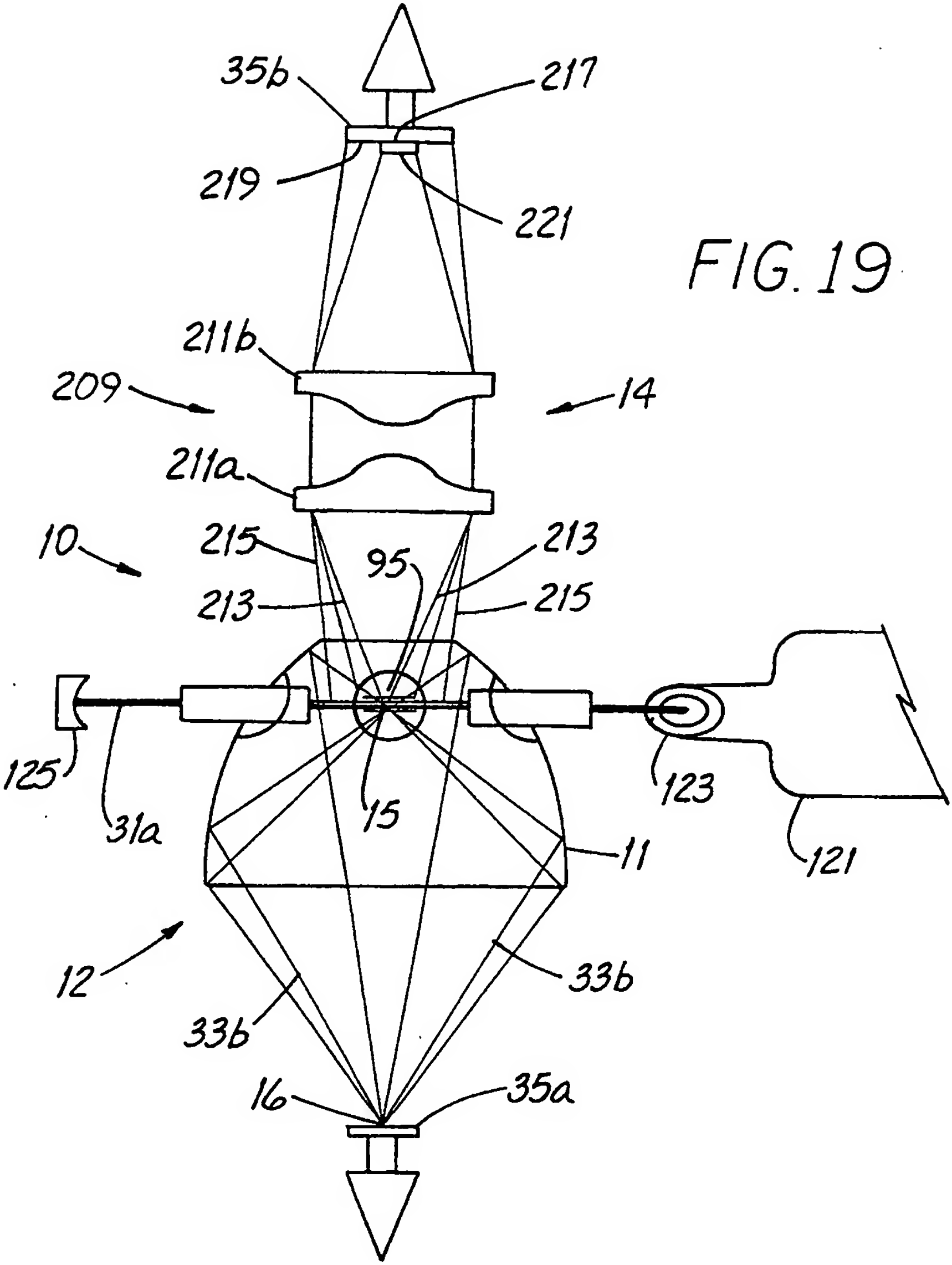
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G01N 15/02, 21/00, 15/06; G01J 3/44

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A , 4,245,910 (KALLANDER) 20 JANUARY 1981, COLUMNS 2 AND 3, FIGURES 1 AND 2	1-2
X	US, A, 5,043,591 (LUDLOW ET AL) 27 AUGUST 1991, COLUMNS 3 AND 4, FIGURES 2 AND 3	6,9,10,11
Y	US, A, 4,140,395 (KREIKEBAUM) 20 FEBRUARY 1979, COLUMN 4 LINES 31-62, FIGURE 1	3
Y	US, A, 3,614,231 (CLYDE C. SHAW) 19 OCTOBER 1971, COLUMN 4 LINES 33-54, FIGURES 5 AND 6	7,8

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 February 1994	FEB 1 8 1994

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer HOA PHAM
Facsimile No. NOT APPLICABLE	Telephone No. (703) 308-4808

Form PCT/ISA/210 (second sheet)(July 1992)★

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

356/39,73,,244,246,301,317,318,335,336,337,338,339,440,441,442,443
250/222.2,574,575

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

356/39,73,,244,246,301,317,318,335,336,337,338,339,440,441,442,443
250/222.2,574,575

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

USPTO APS : (ELLIPSOID? OR ELLIPTICAL OR PARABOID?)
            (SCATTER?(3A)LIGHT)
            (PARTICLE#(3A)DETECT?)
            (PARTICLE# AND GAS MOLECULES)